The Thesis Committee for Miranda Nicole Madrid
Certifies that this is the approved version of the following Thesis:

Monitoring for Resilience: Detecting and Responding to Coastal Wetland Change at the Mission-Aransas National Estuarine Research Reserve

APPROVED BY
SUPERVISING COMMITTEE:

Edward J. Buskey, Supervisor

Kathleen Swanson

C. Edward Proffitt

Lauren Hutch Williams

Monitoring for Resilience: Detecting and Responding to Coastal Wetland Change at the Mission-Aransas National Estuarine Research Reserve

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Miranda Nicole Madrid

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Dedication

This thesis is dedicated to my family—your unwavering belief in me motivates the work I do and desire to make a positive difference. I will always be thankful for your support, prayers, and love.

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Abstract

Monitoring for Resilience: Detecting and Responding to Coastal Wetland Change at the Mission-Aransas National Estuarine Research Reserve

Miranda Madrid, M.S. Marine Sci
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Supervisor: Edward J. Buskey

Climate change poses unprecedented potential for wetland loss and consequences to human communities. It is important to evaluate complex, multi-scale issues, such as climate change, in the context of social-ecological systems. One vital component to resilient social-ecological systems is monitoring—monitoring acts as an effective mechanism for detecting and responding to change in the environment. The primary objective of this thesis was to evaluate the Mission-Aransas National Estuarine Research Reserve's monitoring efforts. Designated in 2006, the Mission-Aransas NERR belongs to a system of Reserves responsible for serving as researchers and educators for their coastal communities across the United States and Puerto Rico. The Mission-Aransas NERR participates in the System-wide Monitoring Program (SWMP), a standard of the system, that collects long-term monitoring data to inform effective coastal management The SWMP consists of standard abiotic and toolbox-approach biotic data collection, sentinel monitoring of sea level rise impacts, and habitat mapping to monitor long-term changes

and short-term variability in estuaries. The first objective was to examine climate-driven foundation species shifts in the salt marsh-mangrove ecotone. In the Mission-Aransas Estuary, there is a general shift toward wetland homogeneity. Wetland sites are becoming less diverse in both species' richness and species evenness. Specifically, black mangrove shrubs and unvegetated covers are increasing in abundance at the expense of succulent and grass species at monitoring sites. The local macroclimate drivers, increasing minimum temperatures and precipitation changes, appear most influential on the estuarine emergent vegetation patterns. The second objective was to understand the role long-term monitoring data plays in management decision-making. Using qualitative methods, this section focused on Mission-Aransas NERR partners who may own or manage lands within the reserve boundaries. Conversations demonstrated the importance of working beyond boundaries to connect long-term monitoring data to management needs. While partners and other stakeholders have utilized water quality data given the freshwater inflow issues of the region, there is an increasing interest in analyzing and learning about non-NOAA funded vegetation, habitat mapping, and elevation data. Leveraging relationships and building community are solutions for connecting data to end users and demonstrating the value of long-term data for multiple use.

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INTRODUCTION

Human impacts, including development, hydrologic changes, and industrial pollution, have historically posed a major risk to wetland existence and health, with the United States experiencing a 30% loss of wetlands from 1780-1980 (Dahl, 1990; Kennish, 2001). This historical vulnerability and renewed emphasis on conservation contributed to a “no net loss” policy of wetland preservation (Dahl, 1990). However, a changing climate now poses unprecedented potential for wetland loss or change in functional structure. The integrity of coastal wetlands, in particular, is increasingly threatened by climate change; climate change exacerbates existing human impacts through the effects of sea level rise, increased annual temperatures, variability in precipitation, and more intense storm events (Intergovernmental Panel on Climate Change [IPCC], 2018). Coastal wetlands are at risk due to their sensitivity to changes in climate and high level of exposure to these changes based on their location at the land-water interface (Finlyason et al., 2017). Climate influences both abiotic and biotic conditions in coastal wetlands, with varying consequences to vegetation abundance, distribution, and diversity (Moomaw et al., 2018).

While climate change impacts will vary across locations, estuarine emergent vegetation, such as salt marsh plants and mangrove shrubs, is at risk of displacement due to sea level rise and tropicalization (Moomaw et al., 2018). In the Gulf of Mexico, sea level rise is widely studied because of its regional importance and large, projected impact to coastal wetlands (Osland et al. 2016; Gabler et al., 2017). If vegetation cannot maintain its elevation through sediment accretion or upland migration due to a hardened shoreline, the changing inundation patterns create conditions of physical stress and wetlands experience “coastal squeeze” (Kelleway et al., 2017; Moomaw et al., 2018). Conversion to open water habitat represents a major loss in vegetated wetlands due to relative sea level rise throughout the Gulf of Mexico (Kennish, 2001), including the Texas coast (Armitage et al., 2015). To develop a comprehensive understanding of emergent vegetation's response to climate change, it is necessary to not only study sea level rise but also other aspects of climate, like temperature and precipitation, especially as they relate to wetlands' ability to adapt to sea level rise (Osland et al., 2016; Gabler et al., 2017). The winter temperature and precipitation gradients along the Texas coast, coupled with its vulnerability to sea level rise, make this an ideal area to monitor the relationship between estuarine emergent vegetation changes and climate drivers (Osland et al., 2016; Feher et al., 2017).

Texas has the potential for large vegetation changes, particularly a shift to mangrove dominance by 2100 (Gabler et al., 2017). Black mangrove (*Avicennia germinans*) responds strongly to temperature, making it a potential indicator species for studying climate change at the marsh-mangrove ecotone, the dynamic boundary between these two foundation habitats. Since the early 1900s, researchers have observed black mangroves in three main concentrations along the Texas coast (Sherrod and McMillan, 1981). Black mangroves are expanding their range poleward beyond their northern latitudinal limit on the Texas coast and are expanding within-range under favorable conditions such as increasing winter minimum temperatures, plentiful rainfall, and low salinity conditions (Sherrod and McMillan, 1981; Montagna et al., 2011; Osland et al., 2013; Armitage et al., 2015). Severe, long-lasting freezes in the 1980's on the Texas coast contributed to massive mortality of mangrove populations though their acreage has since recovered (Sherrod and McMillan, 1985; Montagna et al., 2011). Black mangroves in Texas are the most freeze tolerant black mangroves of the northern Gulf of Mexico due to their narrow xylem vessels that allow them to withstand high-salinity levels and freezing temperatures by reducing embolism occurrence (Sherrod and McMillian, 1981; Madrid et al., 2014).

In addition to black mangrove range expansion, salt marsh species' abundance is also impacted by drought conditions that have the potential to transform grass-dominated marsh habitats to those dominated by succulent species or even bare ground (Osland et al., 2016). Increased salinity stress from less rainfall and high evaporation rates may influence these vegetation shifts (Pennings et al., 2005). Drought conditions, already common in Texas, may become more common under climate change, mitigating the marsh-to-mangrove transition by leading to a dominance in unvegetated cover or succulent species at the expense of black mangroves and/or grass-dominated marshes (Gabler et al., 2017; Osland et al., 2019a). The varying responses of coastal wetland plant types to climate change impacts highlights the need to study them holistically instead of in isolation (Feher et al., 2017; Osland et al., 2019a).

The preservation of existing coastal wetlands is imperative for human communities. As foundation species, black mangroves and various salt marsh plants shape and stabilize their local environment and promote ecosystem functioning (Dayton, 1972; Ellison et al., 2005). While the abundance and subsequent commonality of these species may not make them a focus of conservation efforts, which typically favors rare species, managing and monitoring these coastal foundation species is important (Ellison and Degrassi, 2017; Ellison, 2019). Each wetland ecosystem provides critical functions; both mangrove and salt marsh ecosystems perform important services to the benefit of humans—protection from storm events and sea level rise, climate mitigation, and cultural well-being (Bianchi et al., 2013; Kelleway et al., 2017). Climate-driven vegetation shifts have the potential to alter ecosystem services of coastal wetlands. Mangrove encroachment impacts the faunal composition of wetlands (Smee et al., 2017), decreases vegetation community diversity

(Guo et al., 2017), and may reduce feeding and roosting habitat for migratory shorebirds (Kelleway et al., 2017). The shoreline protection abilities of mangroves relative to marsh vegetation remains uncertain at transition zones (Armitage et al., 2019). Quantifying climate-related shifts in emergent vegetation will assist in understanding the implications to their functioning and ecosystem services provided.

In this study, the spatiotemporal patterns of coastal wetland vegetation were related to climate using long-term monitoring data collected within the Mission-Aransas National Estuarine Research Reserve (NERR) boundaries near Port Aransas, Texas. A range of estuarine wetland types were examined for vegetation community composition, dominance, and presence within individual sites and relative to one another. Monitoring this ecotone has a significant applied importance for management decision-making. The coupling of human and climate drivers may reduce the resilience of coastal wetland ecosystems, or their ability to respond and adapt to disruptions, maintaining their functionality even if their specific structure changes. Long-term monitoring is key to adaptive management—monitoring serves as a mechanism for natural resource managers to receive and respond to feedbacks in the environment (Berkes and Folke (Eds.), 1998). Throughout the Gulf of Mexico, abiotic and biotic differences influence site-specific vegetation shifts with site-specific implications to coastal wetland functioning and ecosystem services, like carbon sequestration (Comeaux et al., 2012; Yando et al., 2016). The nuanced and complex nature of emergent vegetation dynamics is demonstrated through the finding that salt marsh loss is occurring on a regional scale, mainly due to open water and tidal flat conversion, while salt marsh-to-mangrove transitions are occurring more on the local scale (Armitage et al., 2015). Therefore, local, long-term monitoring is imperative to detecting site-specific change and responding appropriately.

METHODS

Study area

This study was conducted within the Mission-Aransas NERR, near Port Aransas, Texas (Fig. 1.1). The Mission-Aransas NERR includes 186,189 acres of open water habitat with oyster reefs and seagrass beds, upland habitats, and a variety of estuarine wetland types, such as salt marshes, tidal flats, and mangroves (University of Texas Marine Science Institute [UTMSI], 2021). The central Texas coast is characterized by warm annual temperatures, variable rainfall patterns, and high evaporation rates. Evans et al. (2012) reported average winter minimum temperatures from SWMP data to be in the range of 8.3-8.9 degrees Celsius with Xue et al. (2015) calculating an average 0.04-degree Celsius increase in average air temperatures per year since the 1970's based on National Oceanic and Atmospheric Administration (NOAA) weather data. Additionally, since the late 1970's, precipitation has decreased 0.5 cm per year, and the Mission-Aransas Estuary continues to experience long periods of drought followed by sporadic, intense rain events (Xue et al., 2015).

The Mission-Aransas NERR participates in the System-wide Monitoring Program (SWMP), a standard of the National Estuarine Research Reserve System (NERRS) in the United States and Puerto Rico, that allows for national and regional spatiotemporal analysis of estuarine conditions (Buskey et al., 2015). The SWMP includes abiotic and biotic data collection, sentinel "early detection" monitoring, and habitat mapping to monitor long-term changes and short-term variability in estuaries (Buskey et al., 2015). The SWMP was designed to collect long-term monitoring data to inform effective coastal management (UTMSI, 2015).

Vegetation Surveys

The Mission-Aransas Estuary is relatively pristine, and wetlands within the estuary are chosen to provide a reference for natural variability and climate changes in the ecosystem (Moore, 2009; Moore, 2013; UTMSI, 2015; NERR Biomonitoring Workgroup, 2020). Vegetation surveys began in 2011 and have grown to encompass four sites (Fig. 1.1). Each site was selected to monitor an impact of interest, such as mangrove encroachment or wind tidal flat recovery. Annual monitoring surveys follow either emergent marsh protocols or mangrove protocols. Long-term monitoring of emergent marsh vegetation follows the NERRS SWMP Vegetation Monitoring Protocol (Moore, 2009; Moore, 2013; NERR Biomonitoring Workgroup, 2020) but has been adapted to protocols used in Texas marshes (Dunton et al., 2001; Forbes and Dunton, 2006). At each of the locations, five transects begin at the water's edge and run 20-meters inland. Each transect is spaced 2-m apart, and each plot along the transect is spaced 2-m apart for a total of 55 permanent plots. Percent cover of plant species, wrack, algae, and unvegetated cover within 0.25 m^2 quadrats is visually estimated at each plot. The stem density and maximum canopy heights of plant species present within the quadrats are also counted and measured. Surveying is conducted annually during maximum biomass, generally late summer to early fall (earliest sampling, August 4; latest sampling, October 24).

Long-term monitoring of mangrove vegetation follows the NERRS SWMP Vegetation Monitoring Protocol (Moore, 2009; Moore, 2013; NERR Biomonitoring Workgroup, 2020) modified from sampling protocols of the Caribbean Coastal Marine Productivity program (CARICOMP, 2001). At one location, five transects begin at the water's edge and run inland. To understand changes in composition and abundance, mangroves and their associated species are studied at different scales. Along each transect, there are four 10 m^2 plots and within each plot, three 1 m^2 subplots, for a total of 20 permanent whole plots and 60 permanent subplots. Percent cover of plant species, wrack, and unvegetated cover within all plot types is visually estimated at each plot. Individual tree measurements, i.e., canopy height and diameter, at whole and subplots are also recorded. Surveying is conducted annually, generally late summer to early fall. However, mangroves are evergreen plants, and sampling can take place in the winter (earliest sampling, September 20; latest sampling, December 18).

Vegetation Statistical Analysis

To understand changes to community composition, foundation species on the established list of vegetation in the study area were identified, and all species were grouped as succulent, grass, mangrove, or unvegetated covers (Table 1.1). Grouping plant species by shared traits, functions or strategies is an effective method for understanding how environmental variables influence their spatiotemporal shifts (Grime, 1974; Boutin and Keddy, 1993; Forbes and Dunton, 2006). Five foundation species are dominant in the central Texas region: *A. germinans*, *Batis maritima*, *Borrichia frutescens*, *Distichlis littoralis*, and *Salicornia depressa* (Osland et al., 2019a; Table 1.1). Emergent vegetation data went through Quality Assurance Quality Control according to the NERR Biomonitoring Workgroup procedures. Any missing or rejected vegetation data were excluded from analysis.

Statistical analyses were done using R 4.1.0 (R Core Team, 2021). To examine temporal patterns of foundation species' composition at individual locations, Bray-Curtis similarity matrices were calculated using percent cover data for quadrats averaged according to their distance from the water's edge. Cover data was square root transformed prior to analysis. To test for significant differences among all years, permutational multivariate analysis of variance, or PERMANOVA, (package: vegan) was performed using the similarity matrices. When there was a significant difference, individual years were analyzed using multiple-comparison testing. To identify which foundation species contributed most to differences in community composition, a similarity of percentages (SIMPER) analysis was conducted using the similarity matrices of the first year's and most recent year's cover data. Finally, to understand the Mission-Aransas Estuary as a whole, non-metric Multidimensional Scaling (nMDS) was used to visualize Bray-Curtis similarity matrices for all sites over time in relation to one another. Again, PERMANOVA was used to test for significant differences and to analyze individual sites and years using multiple-comparison testing. For functional groups, linear models were fit to each site's cover to examine significant trends over time with transects ($n = 5$) as replicates. Biodiversity remains important for maintaining resilience (Berkes and Folke (Eds.), 1998). Thus, diversity is understood using two metrics, species richness and Simpson Diversity Index. Species richness includes the number of species at each site while Simpson Diversity Index includes richness and evenness of the site.

Climate Access

To include local climate drivers, air temperature (°C) and precipitation (mm) data were obtained from two sources, the NERRS' System-wide Monitoring Program and NOAA's National Centers for Environmental Information (Fig. 1.1). SWMP stations within the Mission-Aransas NERR boundaries provide continuous monitoring of water quality, meteorological, and/or nutrient parameters of the bay system. Monitoring began at Copano Bay (East), located in open water near the Copano Causeway, in 2007. Temperature and precipitation data are collected every 15 minutes by an EE181 temperature and relative humidity probe mounted 4 meters off the station platform and a tipping bucket rain gauge on the arm rail 1.5 meters off the platform, respectively.

Meteorological data are available for download on the Centralized Data Management Office (CDMO) website (http://cdmo.baruch.sc.edu/).

To create the most complete climate information, additional air temperature and precipitation data were obtained from NOAA's National Centers for Environmental Information (NCEI) land-based stations. NCEI was formerly the National Climatic Data Center. The Corpus Christi National Weather Service station was selected as having both comprehensive temperature and precipitation data over the entire wetland vegetation monitoring period. Temperature is measured using a Nimbus temperature sensor, and precipitation is measured using a standard rain gage. Both instruments are elevated 13.4 meters. Monitoring began in 2004, and data are produced as daily summaries. Data are available for download on the NCEI website (https://www.ncdc.noaa.gov/data-access).

Climate Statistical Analysis

SWMP meteorological data went through Quality Assurance Quality Control procedures according to the CDMO. NCEI data were integrated with SWMP data. Any missing or rejected data were excluded from analysis. Precipitation data were used to calculate total annual precipitation (mm) for the year prior to each vegetation survey. Data were averaged between the two monitoring stations to calculate the total precipitation. Annual precipitation is important as drought and hypersaline conditions influence shifts in bare ground and succulent species as well as cause dieback of black mangroves (Sherrod and McMillan, 1985; Feher et al., 2017; Gabler et al., 2017). Temperature data were used to calculate freeze conditions during the winter prior to each vegetation survey. Black mangroves respond and dieback due to winter severity, specifically the intensity, duration, and frequency of freezing temperatures. To capture these three elements, the absolute minimum air temperature (Osland et al., 2013; Armitage et al., 2015; Gabler et al., 2017;

Feher et al., 2017), the number of consecutive days with a minimum temperature at or below 0 °C (Armitage et al., 2015), and the number of freeze events (at or below 0°C) for each winter were identified.

To examine vegetation functional groups' response to local precipitation and temperature regimes, Canonical Correspondence Analysis (CCA) was used. CCA is a widely used method for evaluating the relationship between environmental variables and community composition over space and time (Roman et al., 2001). As a constrained ordination, CCA details how much community patterns, composition, distribution, or abundance, can be explained by environmental factors. CCA is performed with an analysis of variance, or ANOVA, with Monte Carlo permutation tests to determine the significance of the aforementioned climate variables influencing functional group patterns in the Mission-Aransas Estuary. These climate drivers have nonlinear and interactive effects on the vegetation response (Osland et al., 2016; Feher et al., 2017).

RESULTS

Individual Sites: Community Composition

The monitoring locations represent a range of estuarine wetland types that are characteristic of the region and of interest to partner landowners managing for vegetation change (Moore, 2013; NERR Biomonitoring Workgroup, 2020). Marsh protocols are implemented at Mud Island-West, three locations at Heron Flats-Aransas National Wildlife Refuge, and Mud Island-East. These sites can be characterized as different wetland types with specific foundation species and covers dominating across the Mission-Aransas Estuary. Mud Island-West was established as a transitional marsh-mangrove location; in its first year of monitoring, 2011, unvegetated cover (~47%) and *A. germinans* (~19%) comprised the majority of cover within plots (Table 1.2). Although Heron Flats has three locations next to one another, the first year's community composition, 2012, was significantly different across locations ($p < 0.05$), and locations are treated individually. Heron Flats is a salt marsh site with succulent and grass species dominating the cover within plots (Table 1.2). Heron Flats 1 had the greatest amount of *B. maritima* (~34%) compared to Heron Flats 2 (~20%) and Heron Flats 3 (~8%). Heron Flats 3 had the greatest amount of *D. spicata* (~67%) compared to Heron Flats 2 (~51%) and Heron Flats 1 (~38%). Unvegetated cover was also in greater abundance at Heron Flats 3 (17%) than Heron Flats 2 (~7%) and Heron Flats 1 (~1%). The last location, Mud Island-East, was established as a tidal wind flat location; in its first year of monitoring, 2018, unvegetated cover (~78%) and *Sporobolus alterniflorus* (~10%) comprised the majority of cover within plots (Table 1.2). The location had been dominated by *S. alterniflorus* prior to sediment burial from Hurricane Harvey in 2017 (pers. communication Katie Swanson).

Since the early 1900s, researchers have observed dense stands of black mangroves at Harbor Island, and isolated stands near Redfish and Aransas Bays in central Texas

(Sherrod and McMillan, 1981). Harbor Island is the single location within the Mission-Aransas NERR where mangrove protocols are implemented. In its first year, 2013, *A. germinans* (~91%) comprised the majority of cover within whole plots while it was also dominant (~80%) in subplots (Table 1.3).

Across their respective monitoring periods, Mud Island-West, all Heron Flats sites, and Harbor Island subplots significantly differed in their community composition (PERMANOVA test, $p < 0.05$; Table 1.4A). Mud Island-East and Harbor Island whole plots experienced interannual variability but this was not significant (Table 1.4A; Fig. 1.4; Fig. 1.5 bottom). At Harbor Island, the whole plot methodology for percent cover may not have allowed the researchers to visualize and record as many species within the predominantly mangrove environment. For those sites with significant differences in their temporal composition, Heron Flats 1 site was the most dissimilar between its first and most recent year's site composition (Table 1.5). Unvegetated cover contributed to the variation in first and most recent year's composition at all locations (Table 1.5) with significant increases at Heron Flats 1 (+91%), Heron Flats 2 (+80%), Heron Flats 3 (+80%), and Harbor Island (+0.7%) (Fig. 1.3; Fig. 1.5 top). At Mud Island-West, *A. germinans* (+32%) increased in cover while *B. maritima* (-7%) and *S. alterniflorus* (-7%) decreased (Table 1.5; Fig. 1.2). *D. spicata* suffered major losses at all sites at Heron Flats with a 33-65% loss in cover within plots (Fig. 1.3).

Mission-Aransas Estuary

Within the Mission-Aransas Estuary, wetland community composition significantly differed among sites and across years (Table 1.4B; Fig. 1.6). Site explained most of the variation in community composition; however, there was significant variation within groups. Within the estuary, functional groups shifted over time as well. All Heron

Flats sites experienced a statistically meaningful positive trend in unvegetated cover (Fig. 1.7). Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg, 2011). Mud Island-West has a positive trend in mangrove cover, but it is not statistically meaningful (Fig. 1.8). Mud Island-West and all Heron Flats sites have a statistically meaningful negative trend in succulent cover (Fig. 1.9). Heron Flats sites have a statistically meaningful negative trend in grass cover (Fig. 1.10). For diversity metrics, species richness, or a change in the number of species present at a site, Heron Flats 2 and Mud Island-West had a negative trend with a loss of two and three species, respectively. Although not statistically meaningful, the negative trend at Mud Island-West was close (Fig. 1.11). To also account for evenness in diversity, change in Simpson Index was statistically meaningful at all Heron Flats sites and Mud Island-West with Mud Island-West experiencing the largest decrease in index by 0.14 (Fig. 1.12). As a predominantly black mangrove site, Harbor Island maintained similar diversity evenness throughout the monitoring period.

Climate and Functional Group Shifts

All climate variables were calculated for the year, so all sites received the same variable for input into the CCA; the exception is 2017 when monitoring was conducted at sites before and/or after Hurricane Harvey (Table 1.6). The mean annual precipitation for the monitoring period (August 2010-August 2020) is 733.2 ± 218.2 mm. Total annual precipitation varied among years; the annual period before the 2013 wetland sampling was the lowest at 461.9 mm and the annual period before the 2015 wetland sampling was the highest at 1,200.2 mm (Table 1.6). For winter severity variables, the winter prior to the 2011 and 2017 wetland sampling had the lowest absolute temperature of -4.4 °C, and 2011 had the longest consecutive series of days with a minimum temperature at or below freezing (Table 1.6). The winter prior to the 2014 sampling had the most freeze events, or distinct times when the minimum temperature was at or below freezing for part of the day (Table 1.6). Freeze events and freeze duration do not indicate freezing temperatures for all 24 hours in a day.

The ordination analysis identified all four climate variables to be important variables that partially explain functional group distribution over space and time (Table 1.7B). The overall model was significant ($p < 0.001$) with all climate variables significantly explaining 5% of the variation (Table 1.7A). Axis 1 had the highest eigenvalue of 0.03. This axis significantly explained 62.6% of the constrained variability and was most associated with total annual precipitation (Fig. 1.13). Only 6.9% of the total variability in functional group distribution was captured in the CCA.

DISCUSSION

A Shift Toward Wetland Homogeneity

The objective of this study was to examine the relationship between coastal wetland vegetation and macroclimate drivers, and how estuarine emergent vegetation is changing in the Mission-Aransas Estuary. Over the past decade, coastal wetland habitats in south central Texas have shifted toward unvegetated cover and black mangrove shrubs at the expense of succulent and grass species (Fig. 1.2-1.10). Black mangrove plants are increasing in abundance at transition zones while remaining dominant in historically dense stands (Fig. 1.2; Fig. 1.5). Unvegetated cover is variable at a few monitoring sites while significantly increasing at others (Fig. 1.2-1.5). Armitage et al. (2015) observed similar shifts on Mustang Island, Texas—mangrove abundance increasing at the expense of salt marsh and other wetland habitats, and salt marsh loss from open water conversion. The Mission-Aransas Estuary is experiencing a general shift toward wetland homogeneity.

Maintaining multiple levels of biodiversity is an important management strategy for building ecological resilience (Berkes and Folke (Eds.), 1998; Patrick et al., 2021). The Mission-Aransas Estuary has a variety of wetland types, with black mangrove shrubs and succulents comprising the majority of functional groups (Gabler et al., 2017). These wetland habitats experience the same climate regimes, and similar fluctuations in functional groups have the potential to increase habitat homogeneity (Patrick et al., 2021). Mission-Aransas wetlands are shifting to have fewer species when only three to six species existed, on average, at the start of monitoring (Fig. 1.11). Diversity loss is also recorded in the decrease in Simpson Indexes for wetland sites as few species are becoming more abundant even if other species can still persist at sites (Fig. 1.12). Although subtle, decreases in foundation species' abundance can lead to functional loss before the complete loss of the species (Ellison et al., 2005).

While the wetland habitats are shifting toward compositional similarity, sites are experiencing both gradual and sudden shifts. At Mud Island-West, 2017 appears to be a tipping point in community composition because, after this year, composition remained significantly different than earlier years, possibly as a response to the major disturbance event, Hurricane Harvey (Fig. 1.2; multiple comparison tests not shown). However, in 2015, community composition appeared more similar to later years. Researchers noted succulent species appearing dead, and black mangrove shrubs as diseased in 2015 and 2016 (NOAA NERRS 2020). While still a transitional site, Mud Island-West is shifting to resemble Harbor Island's dominant mangrove environment (Fig. 1.6). In comparison, Heron Flats sites have experienced gradual shifts in their community composition over the monitoring period. Although significantly different in their first year, Heron Flats sites are similar in composition in more recent years and shifting to resemble the predominantly unvegetated site, Mud Island-East (Fig. 1.6; multiple comparison tests not shown). Most years' composition at Heron Flats sites is dissimilar to others, although later years are generally more similar (multiple comparison tests not shown). With increases in unvegetated cover, specifically water, researchers began recording underwater percent cover of marsh species and seagrass in 2017 and have continued to do so as protocol (NOAA NERRS 2020). While bare ground comprises the majority of unvegetated cover at the Mud Island-East tidal flat, Heron Flats sites are inundated with water (NOAA NERRS 2020).

Climate Drivers on the Central Texas Coast

Local climate conditions remain important sources of influence on functional group shifts in wetland habitats. In the Mission-Aransas Estuary, winter severity and total annual precipitation are important climate drivers of variation in functional group composition.

Wetland sites with mangroves, Mud Island-West and Harbor Island, are associated with higher minimum temperatures and more precipitation (Fig. 1.13). These are favorable conditions in which black mangroves can maintain or expand their abundance (Sherrod and McMillan, 1981; Montagna et al., 2011; Osland et al., 2013; Armitage et al., 2015). Later years of Heron Flats and Mud Island-East sites seem to have shifted away from the frequency and duration of freeze events (Fig. 1.13). The frequency and duration of freeze events may have been more impactful in earlier year's community composition when succulent and grass species dominated, but these variables may no longer have an influence on the unvegetated site. While noteworthy, these climate-related shifts explain a small portion of the variability in the spatiotemporal patterns of the wetland habitats.

Precipitation is an important macroclimate driver as it relates to shifts among vegetation and bare ground. While precipitation is generally uniform over the year, it is projected that the central Texas coast will experience locally intense rain events with longer periods of drought in between under a changing climate (Xue et al., 2015). Thus, precipitation as an event, and not an accumulation, is becoming more relevant to arid regions such as Texas. The nearby Nueces Estuary is impacted by altered freshwater inflows from hydrological impoundments. Dunton et al. (2001) found the timing of precipitation to be important for changes in vegetative cover, especially at low elevations in this salt marsh. Within a short period of time, precipitation events may contribute to a decrease in succulent and bare cover by lowering pore water salinities to an environment more conducive for less salt tolerant vegetation to establish (Dunton et al., 2001). Hurricanes and tropical storms may also act as major disturbances whose effects cannot be fully captured by total annual precipitation. Notably, Hurricane Harvey, a category 4 storm, made landfall on August 25, 2017, within the boundaries of the Mission-Aransas NERR. Major disturbances are important when considering thresholds for ecosystems. As an example, the more sudden shift in community composition at Mud Island-West may be in part due to the effects of Hurricane Harvey. While foundation species shifts were occurring prior to 2017, Hurricane Harvey may have created conditions that did not allow salt marsh species to return to their former abundance (Fig. 1.2; multiple comparison tests not shown). Mangrove shrubs in the dominant stands of Harbor Island suffered loss from high wind damage and seemed to mitigate loss to salt marsh species (Armitage et al., 2019), but similar conclusions cannot be made for the transitional site at Mud Island-West.

Winter severity's impact on black mangroves is captured in the intensity, duration, and frequency of freeze events during the monitoring period. Freezes are another example of a major disturbance that occurs on the Texas coast. Because these disturbances occurred several months prior to vegetation sampling, their effects may not be fully captured in the way other disturbances that occur closer to sampling, such as Hurricane Harvey, are. Severe freezes in 1983 and 1989 contributed to massive mortality of mangrove shrubs (Sherrod and McMillan, 1985; Montagna et al., 2011). The coldest minimum temperature during the monitoring period occurred prior to the first year of sampling at Mud Island-West and in the winter before 2017 (Table 1.6). The increase in mangrove abundance at Mud Island-West during the monitoring period may be an overestimation because this baseline included impacts from the freeze. Although beyond the scope of this study, the recent freeze in February 2021 provides an opportunity to more accurately examine winter severity's impacts on both the dominant and transitional mangrove sites because vegetation sampling occurred immediately after this disturbance event. During the 2021 freeze, air temperatures dropped below -7 degrees Celsius twice, the temperature threshold at which widespread mortality of black mangroves begins to occur (Osland et al., 2013; Osland et al., 2019c). Relative abundance is impacted first while the temperature threshold for presence is even lower (Osland et al., 2013). The microclimate conditions within mangrove environments, such as mangrove canopy cover or height above the soil, on the Texas coast may either protect or damage mangroves from the impacts of freeze events (Osland et al., 2019b).

Even though sea level rise was intentionally excluded from this study, its importance to wetland vegetation shifts cannot be ignored. Relative sea level rise is important to the Gulf of Mexico region (Kennish, 2001; Gabler et al., 2017) and to the Mission-Aransas NERR, specifically. In their 2020 U.S. Sea level Report Card, researchers from the Virginia Institute of Marine Science (VIMS) reported that Rockport, Texas had the second highest annual rise rate of 7.1 mm/year based on NOAA tidal stations across the country (Malmquist, 2021). Sea level rise alters inundation patterns and salinity regimes that impact the presence and abundance of foundation species. Increased inundation periods from extreme high tide events can cause drowning or dieback of vegetation if species do not have appropriate upland migration pathways (Kelleway et al., 2017; Moomaw et al., 2018). At low-latitude marshes, salinity can play a dominant role in shaping estuarine zonation and creating hypersaline conditions in the middle marsh that favor bare ground (Pennings et al., 2005; Forbes and Dunton, 2006). Precipitation interacts with salinity stress to be a driver of vegetation shifts in coastal wetlands (Forbes and Dunton, 2006). Measuring porewater salinity in the root zone of the wetlands would allow researchers to determine the lag time between rainfall events and porewater salinity as well as the salinity differences between dry and wet time seasons. Including porewater salinity and water level changes to analysis would be an important addition for capturing the influence of climate changes to vegetation shifts.

Additional Considerations for Detecting Change

While climate change provides the best explanation for mangrove expansion, biotic interactions inform the extent of the expansion (Silliman et al. (Eds.), 2009). Although the focus of this study was on abiotic parameters, biotic interactions coupled with climate variables allow for the most accurate predictions of range shifts under climate change (Guo et al., 2013). Studies have detailed biotic interactions that lead to the competitive advantage of black mangroves over salt marsh species in Texas such as increased growth responses in high-nutrient waters (Weaver and Armitage, 2018) and propagule entrapment in salt marsh plants that leads to higher rates of successful rooting (Peterson and Bell, 2015). The outcome in dominance is a result of interacting factors of climate, location, age, and salt marsh species' presence that make a determination of encroachment extent more complicated (Guo et al., 2013; Coldren and Proffitt, 2017).

Future Directions

While this study examined two components of SWMP, estuarine emergent vegetation and meteorological data, the Mission-Aransas NERR collects additional data that may lead to a more comprehensive understanding of the vegetation's response to climate changes. Under Sentinel Site Application Module one, or SSAM-1, researchers at the Mission-Aransas NERR detect vegetation's response to changing water levels (NOAA, 2016). Surface elevation tables to measure wetland elevation change and marker horizons to measure vertical accretion coupled with water level recordings offer insight into emergent vegetation's ability to keep pace with sea level rise (NOAA, 2016). Analyzing this data is especially important to relate to major disturbance events, such as Hurricane Harvey, and for Heron Flats sites where submerged vegetation has been recorded for the past few years.

To further understanding of the marsh-mangrove transition zone, researchers may also consider analysis of vegetation measurements not included in this study. Individual tree measurements at Harbor Island and canopy height and stem density measurements at marshes were not evaluated in this study. The repeated examination of select trees at Harbor Island over time provides an additional scale for learning how mangroves respond to unfavorable conditions at the ecotone (NERR Biomonitoring Workgroup, 2020). Canopy height, for example, may demonstrate mangroves' response to less severe freezes in a more detectable way than percent cover measurements do.

CONCLUSION: APPLICATIONS AND IMPLICATIONS

The Mission-Aransas NERR seeks to connect the long-term monitoring of the estuary to the effective coastal management of natural resources. The wetland habitats remain at risk from climate change impacts. The shifts in wetland vegetation communities and their relationship to local climate can provide the information resource managers need to build or maintain resilience in these dynamic environments. In the nearby Nueces Estuary, research and long-term monitoring of emergent vegetation often has a special focus on freshwater inflow requirements for the estuary related to Senate Bill 3 (Dunton et al., 2019). Natural resource agencies have an interest in the work because hydrological impoundments have altered the freshwater inflow to the estuary and have important implications for the emergent vegetation composition and shoreline erosion rates (Montagna et al., 2017; Dunton et al., 2019). The Mission-Aransas Estuary emergent vegetation monitoring serves as a comparison for understanding how the impacted Nueces and pristine Mission-Aransas wetlands respond and adapt to similar climate regimes.

Long-term monitoring in the Mission-Aransas NERR may contribute to applications for and implications to coastal management. This long-term wetland data can inform local decision-making on ecosystem services (Hutchison et al., 2018) as well as the development of tools on a national level for resilience assessments (Raposa et al., 2016). This study has demonstrated a general shift toward wetland homogeneity as the central Texas coast experiences increases in unvegetated cover and black mangroves under a changing climate. These changes highlight the importance of receiving and responding to feedbacks in the environment with an understanding that maintaining historical wetland structures may no longer be possible. There remains a need to monitor for change, not stability and for managers to be willing to adopt new strategies for conservation (Berkes and Folke (Eds.), 2003; Schuurman et al., 2020). Based on monitoring for change, Mission-

Aransas has shifted monitoring protocols in their wetland sites to account for the community composition shifts taking place (pers. communication Katie Swanson). Collaboration and value sharing among scientists, managers, policy makers, and their communities can build resilient coastal ecosystems as these dynamic environments quickly change.

Table 1.1. List of the plant species and covers used in long-term vegetation surveys. Updated names reflect current scientific names. Unknown Identity includes when a species cannot be identified in the field nor in the lab. Unvegetated includes bare, water, and other non-vegetated materials (i.e., marine debris). Foundation species are highlighted with those dominant in the central Texas region highlighted in darker gray (Osland et al., 2019a).

Listed Species and Covers	Updated Species Name	Group
Algae	Algae	Unvegetated
Avicennia germinans (plant)	*Avicennia germinans* (plant)	Mangrove
Avicennia germinans (pneumatophore)	*Avicennia germinans* (pneumatophore)	Mangrove
Batis maritima	*Batis maritima*	Succulent
Borrichia frutescens	*Borrichia frutescens*	Succulent
Canopy Wrack	Canopy Wrack	Unvegetated
Cuscuta sp.	*Cuscuta* sp.	Vine
Distichlis spicata	*Distichlis spicata*	Grass
Iva frutescens	*Iva frutescens*	Succulent
Limonium nashii	*Limonium carolinianum*	Succulent
Lycium carolinianum	*Lycium carolinianum*	Succulent
Monanthochloe littoralis	*Distichlis littoralis*	Grass
Rhizophora mangle	*Rhizophora mangle*	Mangrove
Salicornia bigelovii	*Salicornia bigelovii*	Succulent
Salicornia virginica	*Salicornia depressa*	Succulent
Scirpus maritimus	*Bolboschoenus maritimus*	Grass
Sesuvium portulacastrum	*Sesuvium portulacastrum*	Succulent
Spartina alterniflora	*Sporobolus alterniflorus*	Grass
Spartina spartinae	*Sporobolus spartinae*	Grass
Suaeda linearis	*Suaeda linearis*	Succulent
Unknown Identity	Unknown Identity	Other
Unvegetated	Unvegetated	Unvegetated

Table 1.2. First year's percent cover (mean ± SE) at each marsh protocol location. 0 = not identified at respective location. (n = 55 plots)

Species	First Year's Cover (%)				
	Mud Island-West: 2011	**Heron Flats 1: 2012**	**Heron Flats 2: 2012**	**Heron Flats 3: 2012**	**Mud Island-East: 2018**
Avicennia germinans (plant)	14.85 ± 3.20	0	0	0	2.5 ± 1.7
Avicennia germinans (pneumatophore)	4.55 ± 0.56	0	0	0	0.1 ± 0.1
Batis maritima	6.93 ± 1.93	34.16 ± 3.43	19.89 ± 2.86	8.24 ± 1.57	0
Canopy Wrack	12.85 ± 4.18	1.05 ± 0.54	1.00 ± 0.60	0.05 ± 0.04	8.7 ± 1.5
Salicornia bigelovii	0.04 ± 0.04	0	0	0	0
Salicornia depressa	3.02 ± 1.85	25.85 ± 4.61	19.67 ± 3.46	10.35 ± 2.71	0.6 ± 0.5
Sesuvium portulacastrum	3.75 ± 1.82	0	0	0	0
Sporobolus alterniflorus	7.04 ± 2.63	0	0	0	10.3 ± 1.3
Unvegetated	46.98 ± 4.11	0.82 ± 0.41	7.22 ± 2.67	13.64 ± 4.00	77.7 ± 2.6
Borrichia frutescens	0	0.53 ± 0.31	0.73 ± 0.35	0.25 ± 0.16	0
Distichlis spicata	0	37.51 ± 4.09	51.45 ± 4.09	67.44 ± 4.23	0
Lycium carolinianum	0	0.05 ± 0.04	0.02 ± 0.02	0.02 ± 0.02	0
Unknown Identity	0	0.02 ± 0.02	0.02 ± 0.02	0.02 ± 0.02	0

Table 1.3. First year's percent cover (mean ± SE) at each scale of mangrove protocol location. (10x10 meter, n = 20 plots; 1x1 meter, n = 60 subplots)

	First Year's Cover (%)	
Species	**Harbor Island 10x10: 2013**	**Harbor Island 1x1: 2013**
Avicennia germinans (plant)	77.9 ± 2.9	59.3 ± 3.4
Avicennia germinans (pneumatophore)	12.9 ± 1.3	20.6 ± 1.9
Unvegetated	7.5 ± 1.3	18.7 ± 2.4
Salicornia depressa	1.0 ± 1.0	0.8 ± 0.3
Batis maritima	0.6 ± 0.5	0.6 ± 0.2

Table 1.4. A) Results from PERMANOVA of Year on Bray-Curtis similarity matrices to test for significant differences over time at an individual site. Significant p-values ($p < 0.05$) are noted with an asterisk. Wetland sites are abbreviated: Mud Island-West (MI-W), Heron Flats (HF), Mud Island-East (MI-E), and Harbor Island (HI).

	df	F	P
MI-W	9	2.6886	0.001*
HF 1	9	15.93	0.001*
HF 2	9	14.762	0.001*
HF 3	9	12.929	0.001*
MI-E	2	2.4249	0.096
HI, 10x10	7	1.8127	0.058
HI, 1x1	7	2.6842	0.011*

Table 1.4. B) Results from PERMANOVA of Year and Site on Bray-Curtis similarity matrix to test for significant differences over space and time. Community composition significantly differed over the monitoring period and among the monitoring locations. Significant p-values ($p < 0.05$) are noted with an asterisk.

	df	F	P
Year	10	63.711	0.001*
Site	5	276.213	0.001*

Table 1.5. Results from SIMPER. The following species and covers together explain over 70% of the variation between first year and most recent year of each site. Wetland sites are abbreviated: Mud Island-West (MI-W), Heron Flats (HF), Mud Island-East (MI-E), and Harbor Island (HI). Species and covers that significantly differ between years are noted with an asterisk ($p < 0.05$).

Site	Species	Cumulative Contribution (%)	Average Site Dissimilarity (%)
MI-W: 2011 v 2020	*Avicennia germinans**	33.9	37.9
	*Batis maritima**	51.4	
	Unvegetated	67.6	
	*Sporobolus alterniflorus**	82.3	
HI, 1x1: 2013 v 2020	Unvegetated*	41	11
	*Avicennia germinans**	63.3	
	Salicornia depressa	83	
HF1: 2012 v 2020	Unvegetated*	37.4	80.1
	*Distichlis spicata**	59.7	
	*Batis maritima**	81.5	
HF2: 2012 v 2020	Unvegetated*	35.8	66.1
	*Distichlis spicata**	62.8	
	*Salicornia depressa**	80.7	
HF3: 2012 v 2020	*Distichlis spicata**	38.3	66.1
	Unvegetated*	74.1	

Table 1.6. Climate variables derived from SWMP's 15-minute air temperature and total precipitation and NCEI daily minimum air temperature and precipitation. These variables are used in Canonical Correspondence Analysis. PreH 2017 (Pre-Harvey) = August 22. PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane.

Year	Total annual precipitation (mm)	Absolute minimum temperature (Celsius)	Longest sequence of days with a freezing temperature	Freeze events (# per winter)
2011	533.05	-4.4	6	4
2012	577.75	-3.3	3	3
2013	461.85	-1.1	2	1
2014	560.95	-1.7	3	6
2015	1200.2	0.2	0	0
2016	878.05	1.1	0	0
PreH 2017	694.2	-4.4	3	2
PostH 2017	716.35	-4.4	3	2
2018	685.4	-2.8	5	3
2019	985.85	0.6	0	0
2020	771.6	0.0	1	1

Table 1.7. A) Results from Canonical Correspondence Analysis (CCA). The overall model was significant ($p < 0.05$) but explained little variability (adjusted $R^2 = 0.055$).

	df	Chi Square	F	P
Model	4	0.04350	4.5944	0.001*
Residual	246	0.58224		

Table 1.7. B) Results from CCA testing for marginal effects of variables. All are significant climate variables ($p < 0.05$).

	df	Chi Square	F	P
Freeze.Event	1	0.0118	4.9859	0.014*
Freeze.Day.Length	1	0.00974	4.1139	0.016*
Min.Temp	1	0.00733	3.0962	0.040*
Tot.Precip	1	0.00801	3.3863	0.035*
Residual	246	0.58224		

Table 1.7. C) Results from CCA testing for significant axes. The first axis was significant and explained the most variation (highest eigenvalue).

	df	Chi Square	F	P
CCA1	1	0.02721	11.4954	0.006*
CCA2	1	0.01333	5.6323	0.068
CCA3	1	0.0022	0.9292	0.653
CCA4	1	0.00076	0.3208	0.718
Residual	246	0.58224		

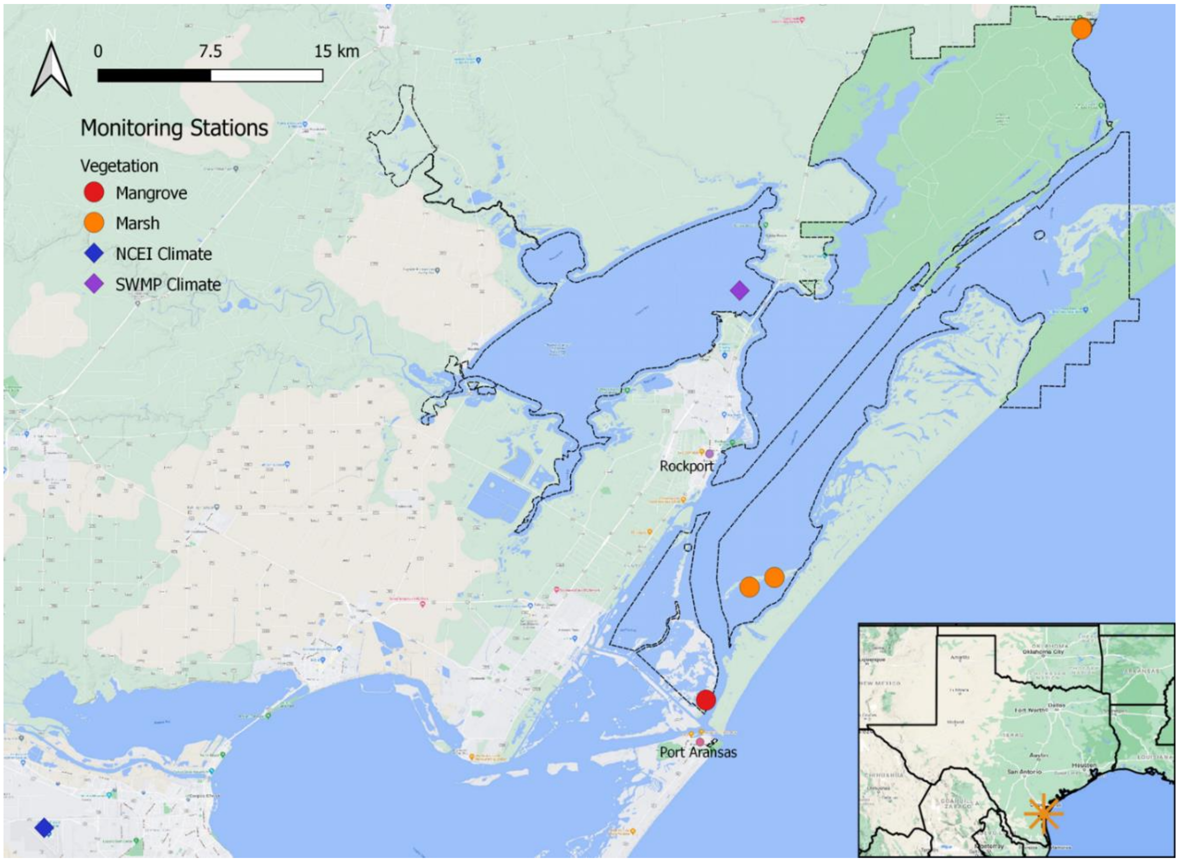

Figure 1.1. Long-term monitoring stations within or nearby the Mission-Aransas NERR Boundaries (dashed line). Estuarine emergent monitoring (circles) consists of mangrove and marsh protocols. Climate monitoring (diamonds) consists of System-wide Monitoring Program (SWMP) water-based and National Centers for Environmental Information (NCEI) land-based stations.

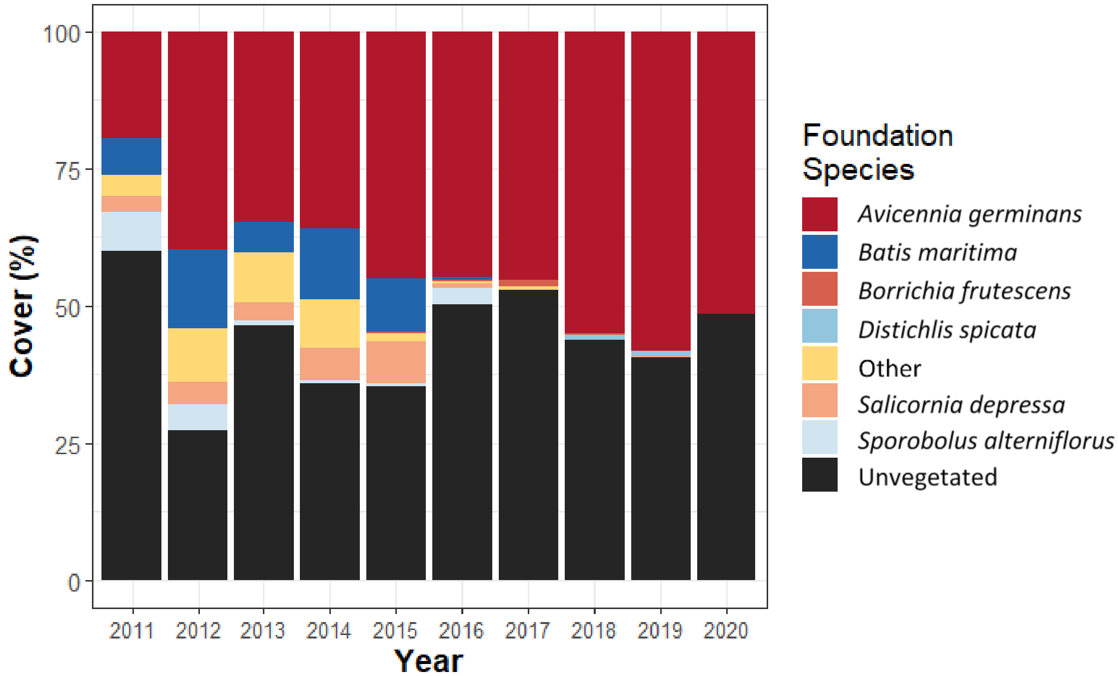

Figure 1.2. Annual community composition of foundation species, unvegetated cover, and remaining plant species (Other) at Mud Island-West from 2011-2020. Community composition was significantly different between years ($p < 0.05$).

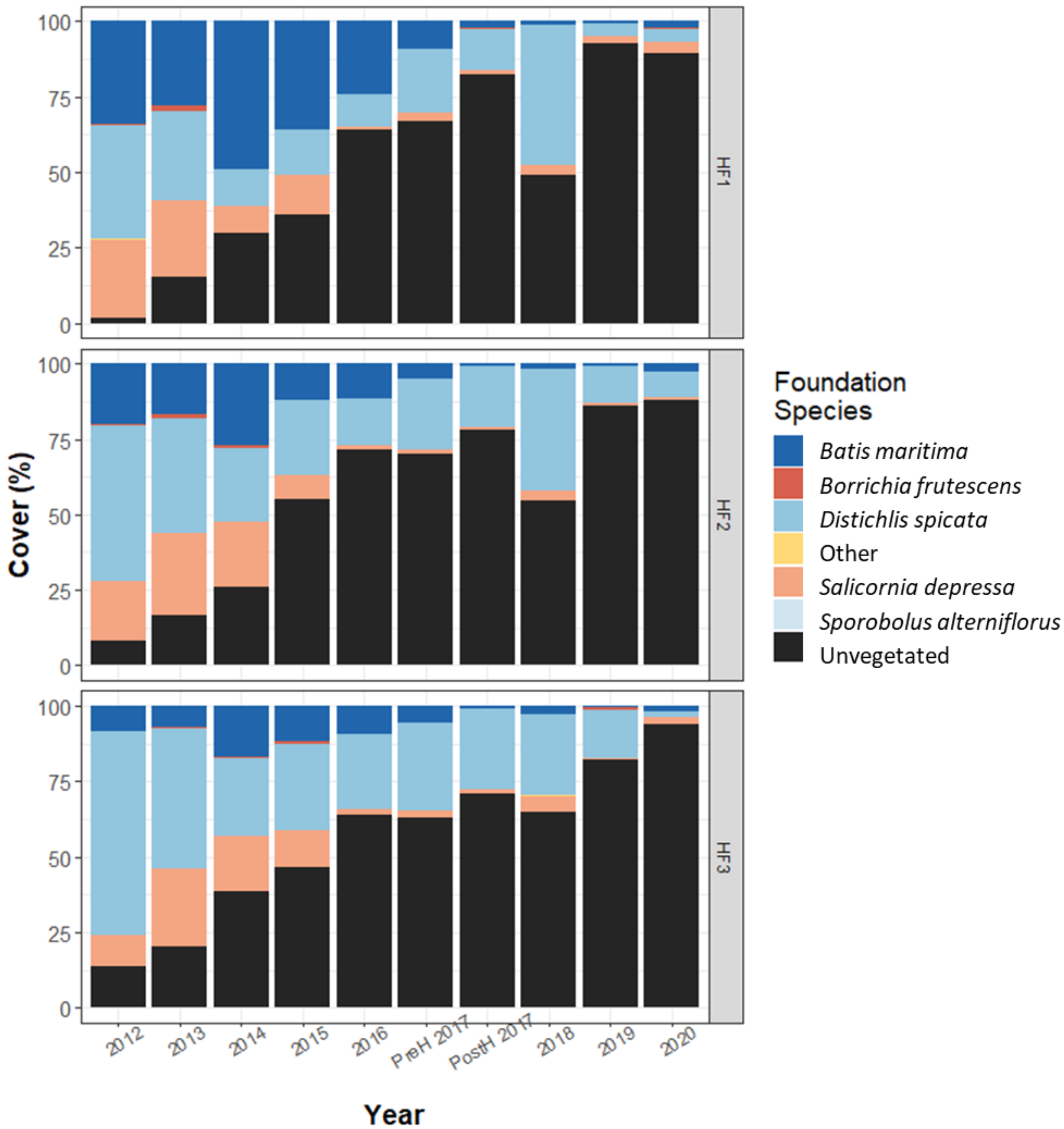

Figure 1.3. Annual community composition of foundation species, unvegetated cover, and remaining plant species (Other) at Heron Flats 1, 2, and 3 from 2012-2020. Percent cover was evaluated twice in 2017 to record composition after Hurricane Harvey. PreH 2017 (Pre-Harvey) = August 22; PostH 2017 (Post-Harvey) = October 16. Community composition was significantly different between years ($p < 0.05$) at each location.

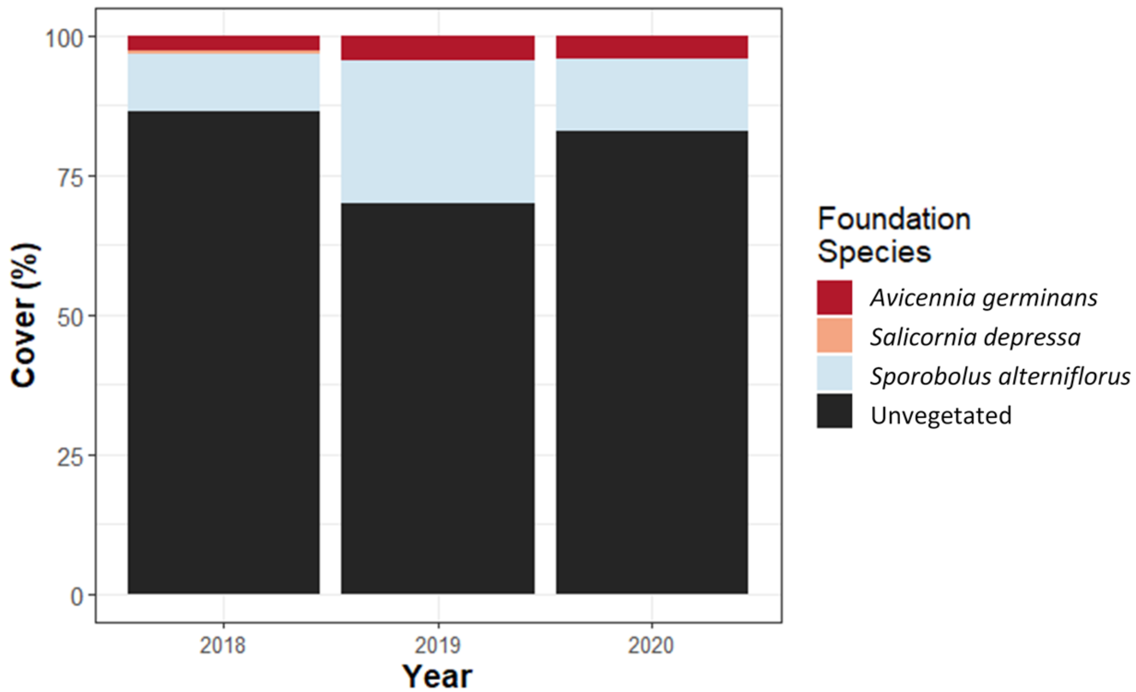

Figure 1.4. Annual community composition of foundation species and unvegetated cover at Mud Island-East from 2018-2020. Community composition was not significantly different between years ($p > 0.05$)

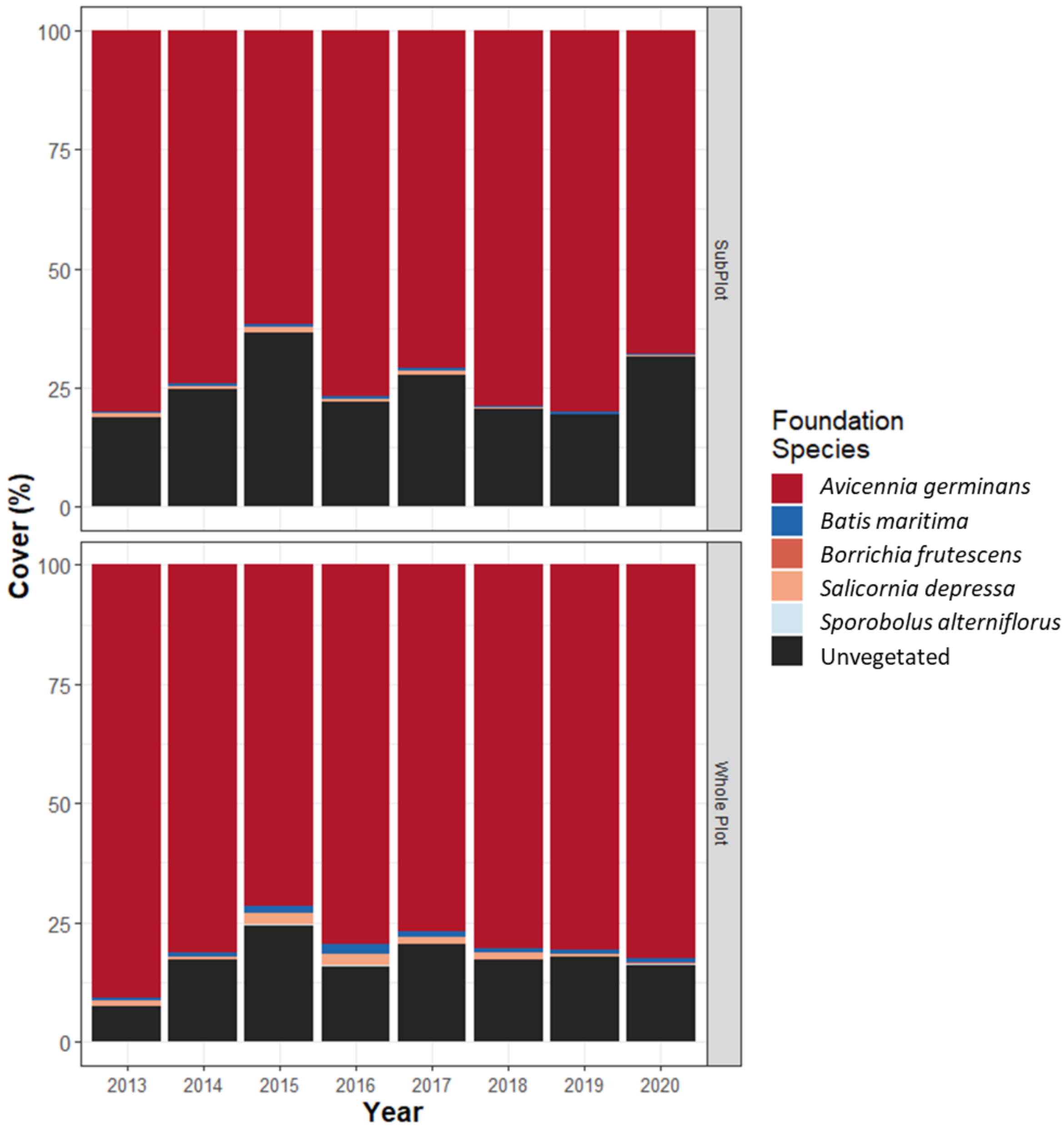

Figure 1.5. Annual community composition of foundation species and unvegetated cover at Harbor Island from 2013-2020. Top: 1x1m, subplot scale. Bottom: 10x10m, whole plot scale. Community composition was significantly different between years in subplot measurements ($p < 0.05$), but not significantly different between years in whole plot measurements ($p > 0.05$).

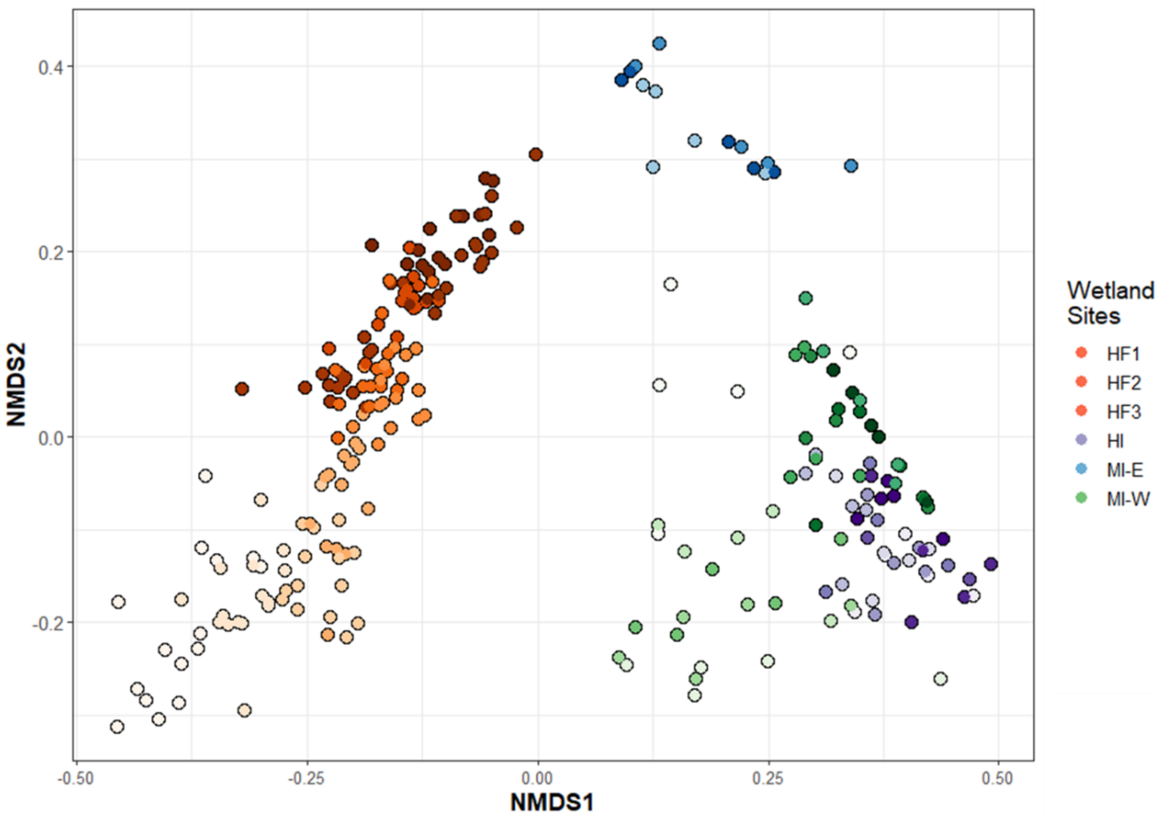

Figure 1.6. nMDS plot of all wetland sites and years. Earlier years (i.e., 2011, 2012) are lighter colors while later years (i.e., 2019, 2020) are darker colors. Stress cutoff = 0.092. Wetland sites are abbreviated and color-coded: Heron Flats (HF), Harbor Island (HI), Mud Island-East (MI-E), and Mud Island-West (MI-W). While Heron Flats and Mud Island-East sites have remained significantly different, Mud Island-West and Harbor Island community compositions overlap in similarity in later years.

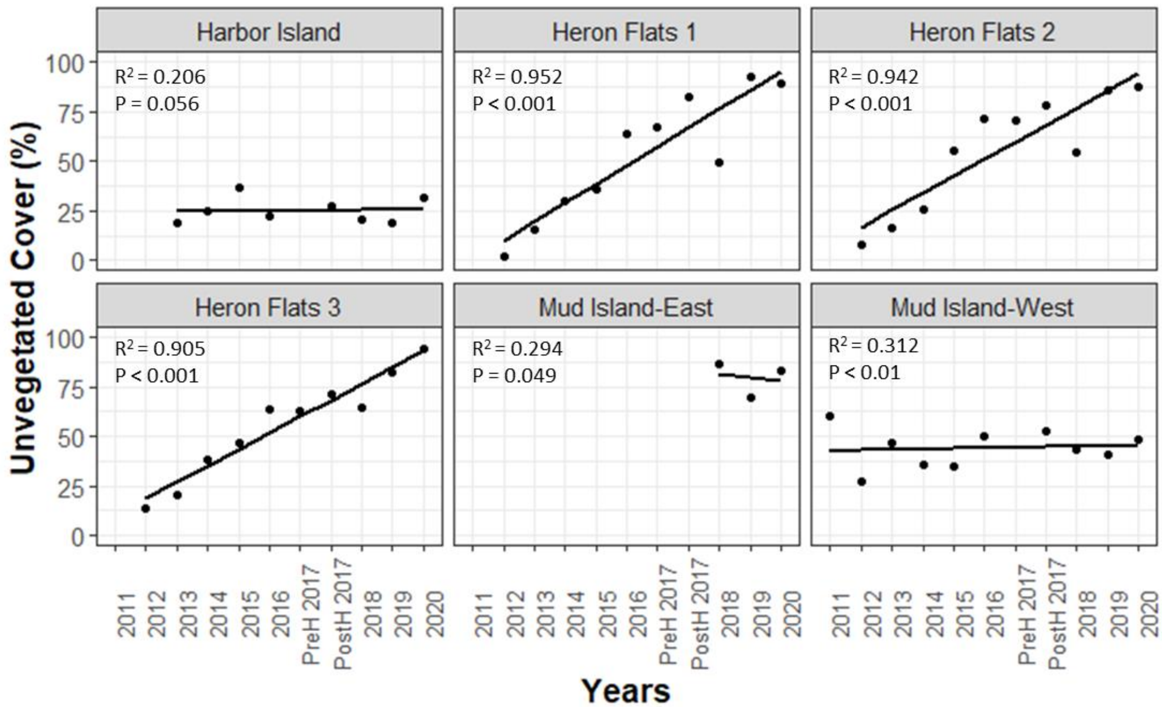

Figure 1.7. Changes in Unvegetated cover (%) over the monitoring periods of each site. Adjusted R^2 and p-values are shown for linear models. Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg 2011). Heron Flats is the only site where sampling occurred twice in 2017, pre- and post- Hurricane Harvey. PreH 2017 (Pre-Harvey) = August 22. PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane. Harbor Island only includes 1x1m measurements.

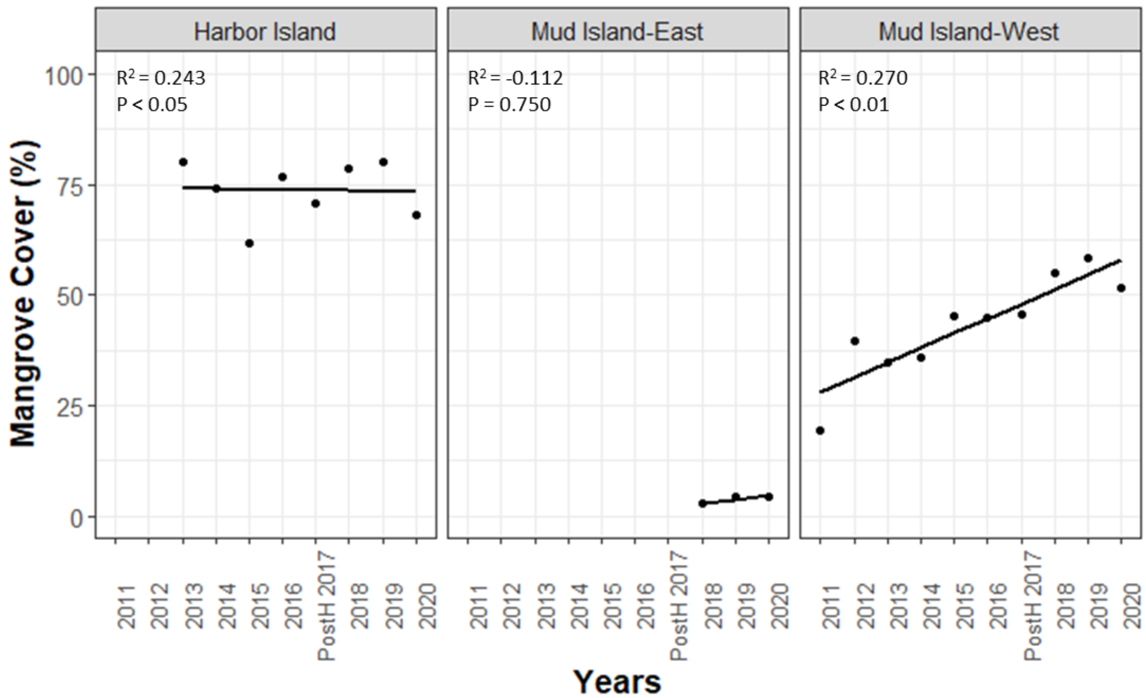

Figure 1.8. Changes in Mangrove cover (%) over the monitoring periods of each site. Adjusted R^2 and p-values are shown for linear models. Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg 2011). PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane. Heron Flats locations did not have mangroves located within permanent plots. Harbor Island only includes 1x1m measurements.

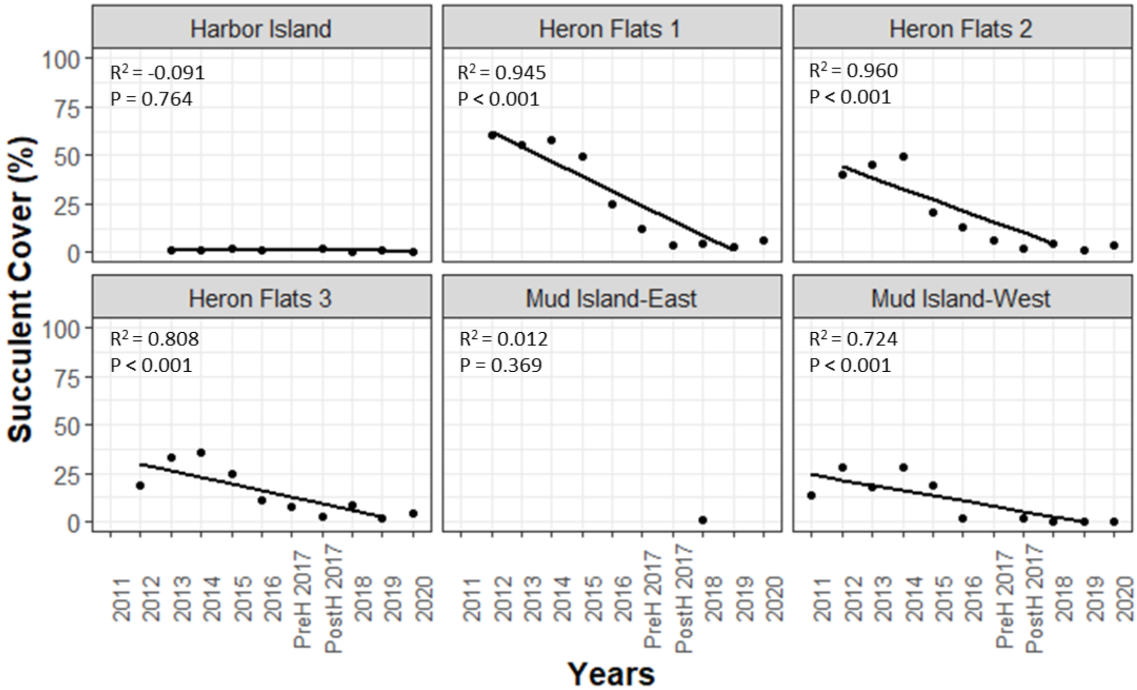

Figure 1.9. Changes in Succulent cover (%) over the monitoring periods of each site. Adjusted R^2 and p-values are shown for linear models. Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg 2011). Heron Flats is the only site where sampling occurred twice in 2017, pre- and post- Hurricane Harvey. PreH 2017 (Pre-Harvey) = August 22. PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane. Harbor Island only includes 1x1m measurements.

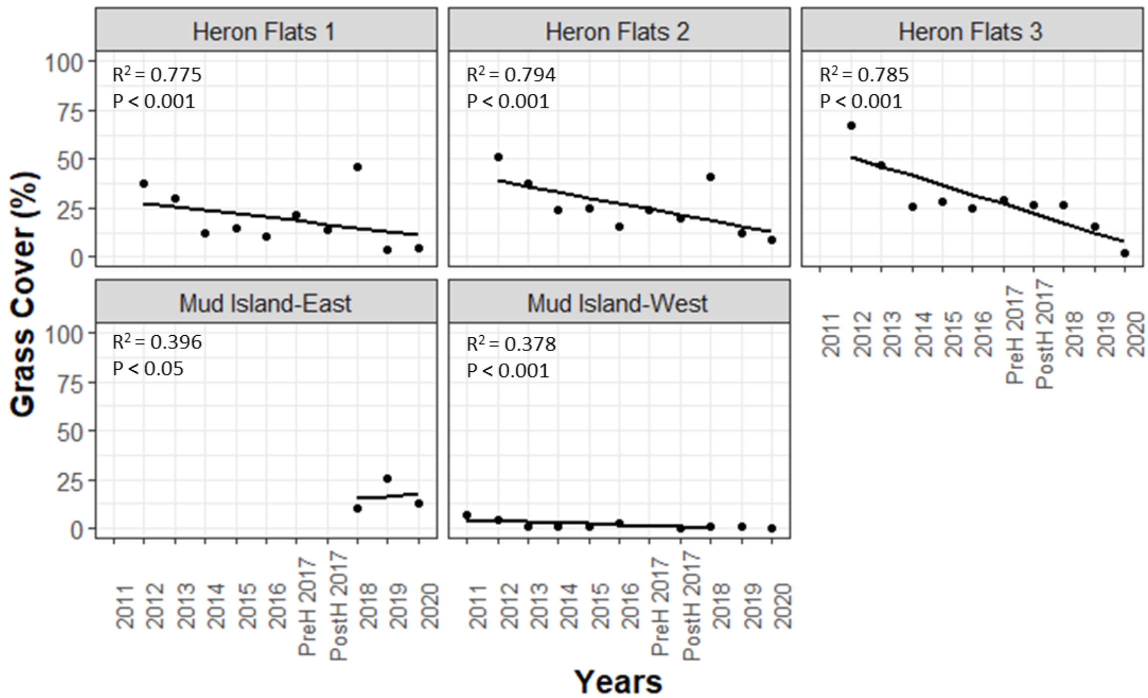

Figure 1.10. Changes in Grass cover (%) over the monitoring periods of each site. Adjusted R^2 and p-values are shown for linear models. Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg 2011). Heron Flats is the only site where sampling occurred twice in 2017, pre- and post- Hurricane Harvey. PreH 2017 (Pre-Harvey) = August 22. PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane. Harbor Island did not have grass species located within permanent 1x1 plots.

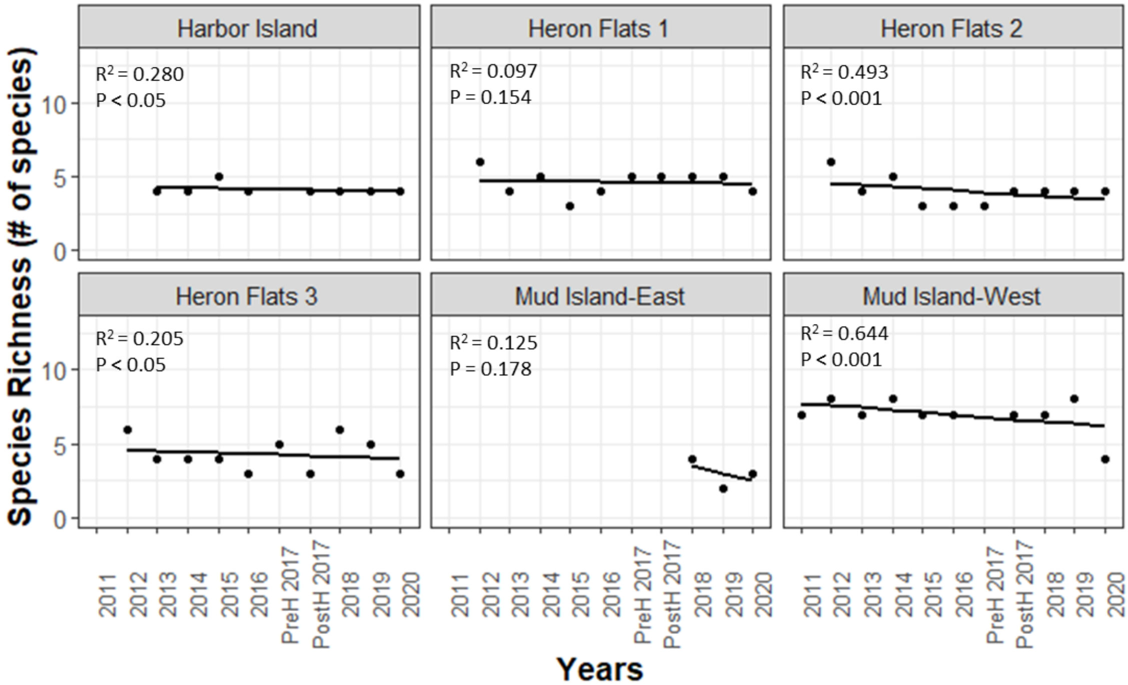

Figure 1.11. Changes in Species richness, or number of species, over the monitoring periods of each site. Adjusted R^2 and p-values are shown for linear models. Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg 2011). Heron Flats is the only site where sampling occurred twice in 2017, pre- and post- Hurricane Harvey. PreH 2017 (Pre-Harvey) = August 22. PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane. Harbor Island only includes 1x1m measurements.

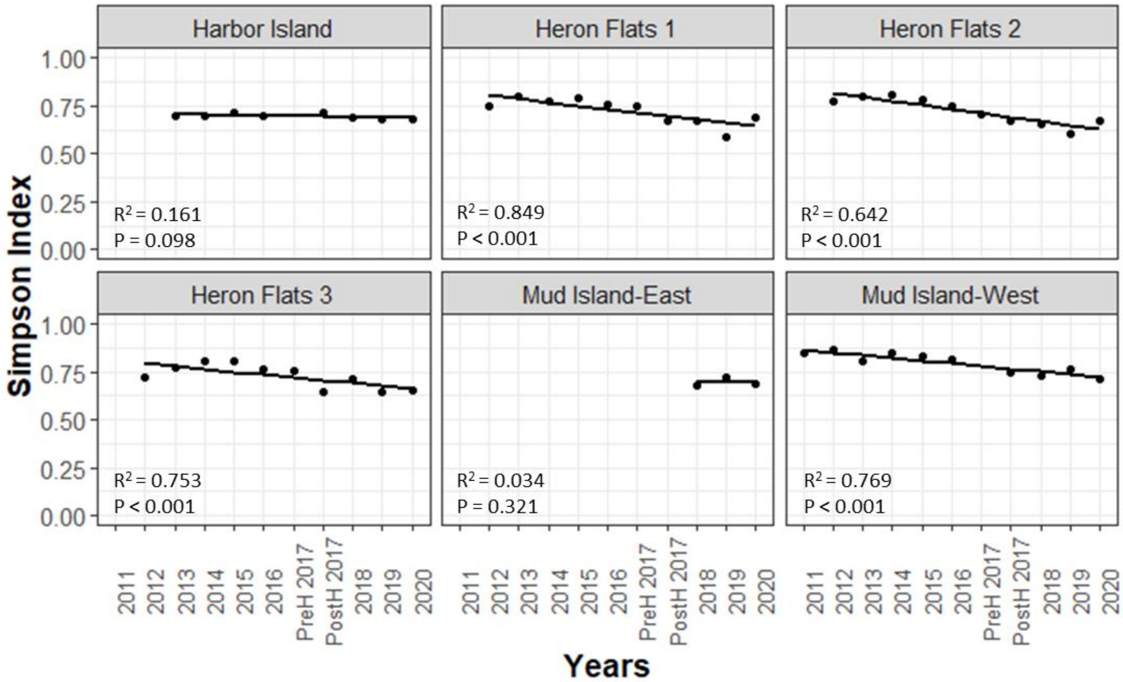

Figure 1.12. Changes in Simpson Index (0-1) over the monitoring periods of each site. Adjusted R^2 and p-values are shown for linear models. Linear trends of averaged time series data are statistically meaningful if $R^2 \geq 0.65$ and $p \leq 0.05$ (Bryhn and Dimberg 2011). Heron Flats is the only site where sampling occurred twice in 2017, pre- and post- Hurricane Harvey. PreH 2017 (Pre-Harvey) = August 22. PostH 2017 (Post-Harvey) is the sampling time for all sites that were sampled after the hurricane. Harbor Island only includes 1x1m measurements.

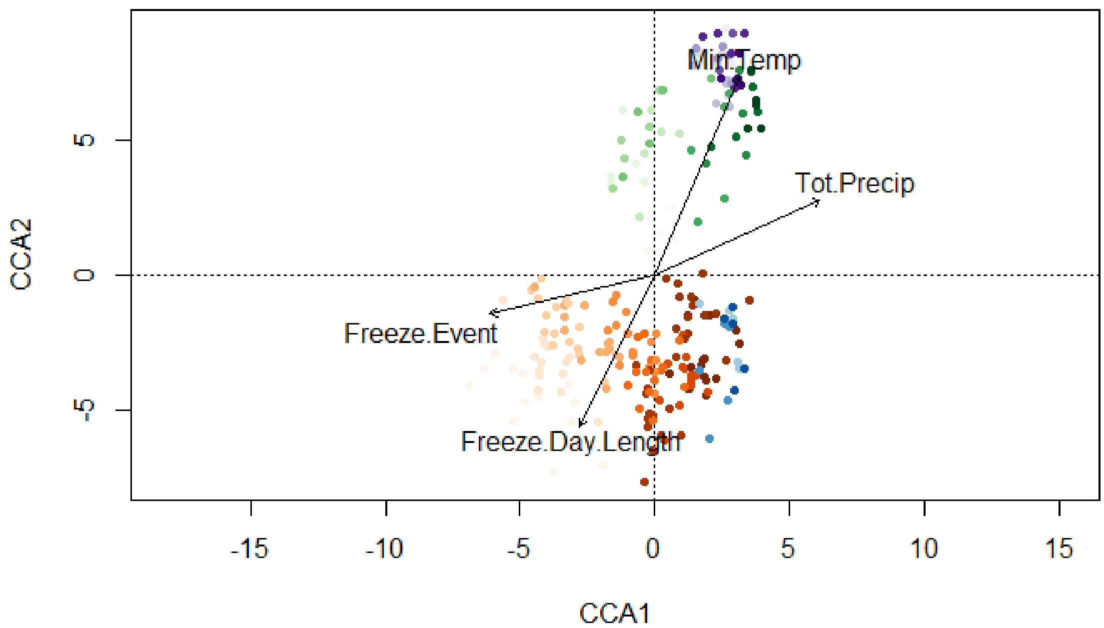

Figure 1.13. CCA plot of wetland sites relationship to four climate variables. Earlier years (i.e., 2011, 2012) are lighter colors while later years (i.e., 2019, 2020) are darker colors. Tot.Precip is total annual precipitation (mm) for the year prior to each vegetation survey. Winter severity includes Min.Temp, the absolute minimum temperature, Freeze.Event, the number of freeze events at or below 0°C, and Freeze.Day.Length, the number of consecutive days with a minimum temperature at or below 0°C.

Chapter 2. Moving beyond boundaries to connect long-term data to management needs at the Mission-Aransas National Estuarine Research Reserve

INTRODUCTION

Human and natural communities face increasing risks under a changing climate. Natural environments are predicted to lose habitats and associated species while human communities will continue to suffer impacts to their health and livelihoods (Intergovernmental Panel on Climate Change [IPCC], 2018). This global problem coupled with regional and local stressors calls for new ways to address challenges and build resilience (Allen et al., 2011; Davies et al., 2015; Schuurman et al., 2020).

Because human and natural systems affect each other, researchers must pay closer attention to the interdependence and feedbacks linking social-ecological systems, i.e., humans-in-nature (Berkes and Folke (Eds.), 1998; Berkes and Folke (Eds.), 2003; Kotchen and Young, 2007). Placing complex, multi-scale issues in the context of social-ecological systems underscores the importance of this standard for responding to challenges in the 21st century (Berkes and Folke (Eds.), 1998; Kotchen and Young, 2007). Natural resource managers play a vital role in addressing these challenges. On-the-ground management is tasked with making sound decisions with high uncertainty and imperfect knowledge (Silliman et al. (Eds.), 2009; Allen et al., 2011). Adaptive co-management blends the strength of partnership among resource users, managers, and decision-makers with learning-by-doing to provide an iterative, flexible way for managers to address “wicked problems” like climate change—defined as complex, uncertain, and ill-defined (Armitage et al., 2009; Berkes, 2009; Allen et al., 2011; Davies et al., 2015). Acting as a liaison between the social and ecological systems, managers must monitor for change, not baseline conditions (Finlayson et al., 2017; Schuurman et al., 2020) and have ongoing efforts in place to detect temporal and spatial change and variability. Monitoring is an effective mechanism for detecting and responding to change (Berkes and Folke (Eds.), 1998)—improving the adaptive capacity of a system and the response time of local management (National Oceanic and Atmospheric Administration [NOAA], 2016).

Management is a decision-making process (Nichols and Byron, 2006), and monitoring provides the structure to learn about the environment, assess conservation success, and take action (Lindenmayer and Likens, 2009; Allen et al., 2011; Salafsky et al., 2019). Monitoring informs management decisions, and, in turn, management needs inform monitoring protocols (Schuurman et al., 2020). Consistent monitoring over many years can lead to a collection of long-term information needed to understand historical and current environmental conditions. Long-term monitoring is necessary to interpret ecological processes that function over long time periods (Callahan, 1984; Hughes et al., 2017). By building a history of species and ecological processes for an environment (Callahan, 1984), long-term data collection can lead to the identification of trends and shifting baselines and new understandings of ecological concepts (Hughes et al., 2017). While scientists and managers acknowledge a need for and importance of long-term research (Lindenmayer and Likens, 2009), a variety of stakeholders, including policymakers (Hughes et al., 2017), also benefit from long-term monitoring data (Callahan, 1984).

While monitoring may be an important tool for understanding climate change impacts and planning for adaptation (Finlayson et al., 2017), natural resource managers may not have the capacity and broad commitment to conduct long-term monitoring (Callahan, 1984). Prior to monitoring, managers must attempt to tie the future data to relevant scientific questions that will be useful for their decision-making (Callahan, 1984; Maxwell et al., 2015). However, even if the future data proves useful, managers may face barriers implementing their monitoring-informed-decisions if they do not align with their institution's vision and goals (Hansen, 2014). Limited by time and money, managers may decide that resources are better spent managing than gaining knowledge (Maxwell et al., 2015; Bennett et al., 2018). Managers may only want to take action once monitoring data is analyzed through the adaptive management process (Lindenmayer and Likens, 2009) but waiting to detect a significant trend in statistical analysis can require lots of data which takes time (Nichols and Byron, 2006). In particular, climate change effects can be classified as "subtle and gradual" or "abrupt and discrete" making it more difficult for managers to detect and define associated problems (Gray et al., 2014). Historical datasets may not inform the future as they once did (Callahan, 1984; Finlayson et al., 2017); conserving baseline conditions may no longer be realistic under a changing climate, and managers, instead, have to make conservation decisions guided by values (Finlayson et al., 2017; Schuurman et al., 2020).

The purpose of this study is to understand how long-term monitoring contributes to management decision-making at the Mission-Aransas National Estuarine Research Reserve (NERR) in Port Aransas, Texas. The Coastal Zone Management Act established the National Estuarine Research Reserve System (NERRS) as research centers for studying coastal land, waters, and natural resources (92nd U.S. Congress, 1972). To balance the economic, recreational, and ecological importance of these coastal regions, the federal government highlighted the need for national, state, and local coordination of the NERRS (92nd U.S. Congress, 1972). The Notice of Designation of the Mission-Aransas NERR in Texas (2006) established the University of Texas at Austin Marine Science Institute (UTMSI) as the state partner. The Mission-Aransas NERR operates the System-wide Monitoring Program (SWMP), a set of standardized protocols within the NERRS across the United States and Puerto Rico. Established in 1995, the SWMP includes abiotic and biotic data collection, sentinel "early detection" monitoring of sea level rise impacts, and habitat mapping to monitor long-term changes and short-term variability in estuaries (Buskey et al., 2015). With a diversity of Reserve locations across the country, researchers can conduct national and regional spatiotemporal analyses of estuarine conditions (Buskey et al., 2015) to develop a better understanding of macroscale processes (Patrick et al., 2021). The place-based nature of the Reserves means staff focus on the local needs and issues surrounding their communities. The data collected and analyzed within the SWMP is meant to address these significant coastal issues and inform effective coastal management (UTMSI, 2015). With NOAA as the federal partner, the Mission-Aransas NERR and SWMP have both national direction and local relevance.

To examine the role SWMP data plays in coastal management decisions in Texas, this study takes a qualitative methods approach. An in-depth evaluation of a research program can elicit perspectives, barriers, and guidance for making science actionable (Cvitanovic et al., 2016). An evaluation of the process and impact of the SWMP at the Mission-Aransas NERR aligns with the broader NERRS' interest in connecting SWMP data to management needs (Eastern Research Group, Inc. [ERG], 2017) as well as the Mission-Aransas NERR's goals of enhancing SWMP and integrating SWMP data across sectors (UTMSI, 2021). In using the Mission-Aransas SWMP as a case study for understanding long-term monitoring and management decision-making, the goal is to better understand this particular program in a management context, and not necessarily to generalize to other long-term programs (Stake, 1989; Lichtman, 2014). Effective monitoring is one aspect for building social-ecological system resilience (Allen et al., 2011; Finlayson et al., 2017) which is important to the NERRS' mission.

METHODS

Study Site

This study was conducted at the Mission-Aransas NERR, at Port Aransas, Texas (Fig. 2.1). The Mission-Aransas NERR includes 186,189 acres of open water habitat with oyster reefs and seagrass beds, upland habitats, and a variety of estuarine wetland types, such as salt marshes, tidal flats, and mangroves (UTMSI, 2021). The Mission-Aransas NERR is a dynamic ecotone with changing temperature and precipitation patterns. While coastal woody encroachment of black mangroves is a relatively recent and nuanced issue (Armitage et al., 2015), the region has ongoing issues concerning freshwater inflows and erosion (Dunton et al., 2019). The counties within the Mission-Aransas NERR watershed have historically been characterized as rural with limited industry (Morehead et al., 2007); however, population growth and industrial influence are becoming more of a concern to decision-makers (Dunning, 2019).

The Mission-Aransas NERR's mission is "to promote healthy, resilient coastal communities and estuaries through an integrated program of research, education, and stewardship" (UTMSI, 2021). The SWMP is part of this mission as it contributes to the quality of scientific information to promote this healthy and resilient social-ecological system. UT-Austin directly owns or manages lands associated with the Marine Science Institute and educational facilities (i.e., Bay Education Center) totaling 31 acres (UTMSI, 2021). All other acreage within the Mission-Aransas NERR boundaries is owned or managed by external stakeholders; however, Fennessey Ranch (3,261 acres) is a private business with a conservation easement owned by UT-Austin. The Mission-Aransas NERR has the crucial responsibility of communicating results to those external end users with management authority over the estuarine habitats.

Respondent Selection and Data Collection

In preparation for the study, an Institutional Review Board (IRB) proposal for human subjects research was submitted to the IRB of the University of Texas at Austin and approved (Appendix A). All interviews and focus groups were conducted over Zoom video platform due to the COVID-19 pandemic, and a single researcher was responsible for conducting the interviews and focus groups. The groups listed in the following sections were selected as they have authority to implement the recommendations of this study and have decision-making authority over the natural resources within the Mission-Aransas NERR boundaries. The evaluation was conducted in three stages: Mission-Aransas NERR staff interviews, partner organization focus groups, and national NERR representative interviews. All conversations occurred during February to May of 2021.

Mission-Aransas NERR Staff: Interviews

The first stage of qualitative methods began with current Mission-Aransas NERR staff. All staff members were invited via email to take a survey through Qualtrics, an online survey tool. The short survey was designed to determine a staff member’s familiarity with and participation level in SWMP (Appendix B). Staff who completed the survey within two weeks of its distribution were invited for a follow-up interview scheduled for one hour. In-depth interviewing is an important method for understanding the meaning of a topic, like SWMP, to respondents (Murphy, 1980). The interview guide took a semi-structured nature in which the interviewer had a set of pre-determined questions but was not required to ask all questions and could ask for clarifications and elaborations. To start the interview, the interviewer reviewed informed consent with the interviewee and obtained their verbal consent. Interview questions were categorized to learn about the staff member’s perceptions on long-term monitoring and SWMP, partners’ and external users’ use of

SWMP data, and barriers to and solutions for a successful program (Appendix C). After the interview, staff interviewees received a thank you email for their time and a list of 32 management partner individuals. They were asked to recommend additional individuals who were not on the list, identify priority individuals, or identify individuals to be removed. Staff identified 11 priority individuals. Originally, the list included many more individuals as the first task was creating an extensive list of people to consider for conversations about SWMP. Based on the study's timeline, the list was later narrowed to include individuals whose organization is represented on the Mission-Aransas NERR's Reserve Advisory Board (RAB).

Partner Organizations: Focus Groups

Organizations represented on the RAB include nonprofits, federal and state agencies, and local government officials (Table 2.1). Because these organizations are responsible for guiding and advising the Mission-Aransas NERR activities, they were considered to have greater familiarity with programming, such as SWMP, and have a strong interest in participating in the study. Several of the RAB partner organizations are responsible for the management of natural resources within the Mission-Aransas NERR boundaries.

After Mission-Aransas NERR staff interviewees reviewed the list, email invitations were sent to 31 partner individuals to join a brief webinar. At this webinar, participants were introduced to this study and shown example data visualizations on wetland vegetation for their opinions. The webinar was for recruitment purposes only, and responses during the webinar are not part of this study's data analysis. Additional referrals during the webinar led to 33 email invitations to join the focus groups. Focus groups are an effective method for gathering information from several people in a short amount of time (Berg, 2009). Focus groups provide a space where participants can build off of each other's responses; the group dynamic means new ideas and more thoughts can be developed (Berg, 2009). Focus groups were scheduled for an hour and a half. The focus group guide took a semi-structured nature in which the facilitator had a set of pre-determined questions but was not required to ask all questions and could ask for clarifications and elaborations. To begin the focus group, the facilitator reviewed informed consent with the group participants and ensured everyone understood the norms for virtual groups (i.e., turning off phones, listening respectfully). Focus group questions were categorized to learn about partners' perceptions on management and long-term monitoring, their use of SWMP data, their own organizations' long-term monitoring programs, and barriers to and solutions for successful monitoring (Appendix D). Focus group participants received a thank you email for their time.

National NERR Representatives: Interviews

The third and final stage of qualitative methods ended with national NERR representatives. These individuals have a working knowledge of operations on the national level and can offer system-wide perspectives. Interviews with Mission-Aransas NERR staff members and initial data analysis highlighted the need to contextualize these place-based conversations. Although not originally a study population, a decision was made to identify and include individuals working at the national level of the NERRS. These representatives were invited via email to participate in an interview scheduled for one hour. In-depth interviewing is an important method for understanding the meaning of a topic, like SWMP, to respondents (Murphy, 1980). The interview guide took a semi-structured nature in which the interviewer had a set of pre-determined questions but was not required to ask all questions and could ask for clarifications and elaborations. To start the interview, the interviewer reviewed informed consent with the interviewee and obtained their verbal consent. Interview questions were categorized to learn about the individual's perceptions of SWMP and how it connects to the NERRS, and barriers to and solutions for a successful program at a national level (Appendix E). Interviewees received a thank you email for their time.

Data Analysis

All interview and focus group recordings were transcribed using Zoom's audio transcription feature, and transcripts were reviewed for accuracy. The NVivo software, a research tool for storing, transcribing, and visualizing qualitative data, was used to code transcripts. The transcripts from each group of respondents—Mission-Aransas NERR staff, partners, and national NERR representatives—were coded for themes within their respective group. While interviews represent the interviewee's perceptions, the responses in the focus group arise as a discussion, and the results are group perceptions (Berg, 2009). Therefore, focus group transcripts were analyzed as group conversations. Thematic coding had elements of grounded theory methods, an inductive system of collecting and analyzing data to build theory. For example, initial analysis of Mission-Aransas NERR staff responses drove subsequent data collection in the form of revisions to the later groups' questions and prompts (Charmaz, 2004).

To interpret responses, initial coding of the transcript data was done, and descriptive codes were assigned to text resulting in a large number of initial codes—over 50 (Bailey, 2018; initial codes not shown). These initial codes were then grouped into themes relevant to the program evaluation and redefined as necessary (Bailey, 2018). The objective for the data analysis was to draw out common themes related to the categories of long-term monitoring in a management context, perceptions of SWMP and NERRS, and barriers to and solutions for a successful monitoring program. Similar to grounded theory, initial codes emerged from the data (Charmaz, 2004); however, categories of themes were based on the aforementioned objective for data analysis. Extraneous themes are not included in the results if they did not relate to the categories. The number of groups or interviewees that spoke of a theme was identified (see Tables). To establish commonality, more than one person had to speak of a theme for it to be included in this study. Drawing out and identifying mental models, or ways of thinking about a concept, is not only useful for understanding people's assumptions but may also help with collaboration challenges those different stakeholders face (Biggs et al., 2011). Because mental models are not fixed, sharing how respondents think about a concept can provide a new idea or lesson learned for others (Jones et al., 2011). Similarities and differences in the three groups' way of thinking about SWMP and long-term monitoring are identified, and recommendations are made for the Mission-Aransas staff to engage stakeholders in their monitoring efforts.

RESULTS

Mission-Aransas NERR staff

Seven staff members completed the Qualtrics survey within two weeks of its distribution. These staff members represent the various sectors of the Mission-Aransas NERR (results not included for confidentiality) which allowed different SWMP perceptions based on their positions. Six staff members noted that they participate in communication activities regarding SWMP which was the most frequently cited monitoring activity (Fig. 2.2). All seven were invited for a follow-up interview and agreed to participate.

Within the broader context of the south-central Texas community and beyond, Mission-Aransas NERR staff identified the importance of themselves and the Mission-Aransas Estuary as representative of their mission to conduct and communicate science (Table 2.2: Role of Mission-Aransas). Discussing the Mission-Aransas Estuary, one staff member noted:

> *Relatively speaking, ours is pretty pristine. It's nice to have that, especially when you're comparing it to some of the other [estuaries] where they're near big cities, and they have a lot of other inputs and just pollution. So, this is the standard to keep track of, and hopefully we can keep it in good shape.*

Other staff were in agreement that an indicator estuary like the Mission-Aransas serves an important purpose for monitoring long-term ecological processes and climate change. Beyond the physical environment's importance, staff members also viewed themselves as a scientific support for the region. The Mission-Aransas NERR is grounded in scientific understanding of the Mission-Aransas Estuary which translates to the outreach that extends to a broader audience than purely scientists. As one staff member observed, "*I feel like the NERR is built on research so it's something that drives it. It's something that makes it legitimate.*" As primary conductors of the science, the staff then takes the information into their programming which is unique compared to other science communication institutions without in-house research programs. Moreover, the staff is conducting the science to support those who need science to take action, such as state agencies.

Long-term monitoring remains important to the Mission-Aransas NERR as staff members are responsible for implementing and operating the local SWMP. Long-term monitoring serves a variety of purposes to the staff ranging from its connection to decision-making to the inherent importance of creating an ecological history of the Mission-Aransas Estuary (Table 2.2: Importance of long-term monitoring at the MANERR). Developing a baseline database serves two purposes. Staff believe that establishing a history of the area means researchers can look backwards to draw meaning of current conditions. This longer history provides a perspective on short-term variability versus longer term trends. The baseline database can also be used to look to the future and track the trends and impacts of climate change. As extreme events become more common under climate change, one staff member reflecting on Winter Storm Uri, a major winter and ice storm that occurred February 13-17, 2021, said:

> *We're going to do that mangrove monitoring because something like this hasn't happened in a long time. […] We have previous data, baseline data, and then, all of a sudden, you have an event like this. It's a really good opportunity for us to use our SWMP platform to document what's happening.*

Tracking estuarine change in the context of climate change is important to several staff members. Long-term monitoring data complements other methodologies and can point to the need for more research. Analysis of the monitoring data may produce more research questions in the process of answering questions. Analysis of the monitoring data may also serve as confirmation or another piece of evidence to the visual assessment of estuarine change. In general, the importance of long-term monitoring appeared to be based more in scientific understanding of an environment than application of the data. While a couple staff members explicitly mentioned the connection of long-term monitoring to decision-making, it was often vague such as, "*hopefully, we're using that data to then inform ourselves and decision-makers, policymakers, of what to do next to help our environment.*"

With attention to the System-wide Monitoring Program, staff offered their perspectives which represented how their positions within the organization influence their opinions of the program (Table 2.2: SWMP Perceptions). The high-quality database is a source of pride for the Mission-Aransas NERR. Consistent fieldwork by the staff and training and data management offered by the Centralized Data Management Office (CDMO) support this robust dataset. However, these strong upfront efforts have the potential to take time away from the later efforts needed to analyze and communicate the SWMP data. One staff member viewed staff efforts as, "*we do the monitoring really well, but then, we're not going to the next level with it. We're not analyzing it. I don't think we disseminate the data well enough. I don't think we're able to get our message across.*" This emphasis on a communication weakness is important because the majority of staff interviewed had identified their role in communication. Several staff members described their SWMP communication as embedded within their general communication of the Mission-Aransas NERR, and therefore, they do not provide a comprehensive account of the SWMP. Communication can take the form of informal presentations to adult groups, presentations at academic conferences, or school groups visiting the estuary. While those sectors most involved with data collection may have more focused communication on SWMP protocols and results, this is not the norm. The SWMP may be embedded within general Mission-Aransas NERR communication and become overlooked because it is some of the staff's perception that the program is not the most exciting part of their work. One staff member summed up the balance between the research's importance with other, more engaging programs:

It’s hard to get the public interested in just data and research, but when you have this whole thing, then people are interested in the turtles and interested in helping and want us to keep going. I think every aspect of the NERR has such a big role in moving us forward and keeping us relevant. Because when it's just data, that is okay, and that's great, and that's the most important thing to keep monitoring, but when you have all these different roles, I think it keeps it relevant and keeps the public engaged.

While SWMP is core to the Mission-Aransas NERR’s mission, additional staff described the work as more of a checklist to keep the program running and were disconnected to using the SWMP in their personal work.

Staff had several examples to provide for uses of the SWMP data (Table 2.2: Impact- Known and Potential Uses of SWMP data). Long-term water quality data and real-time data on the CDMO’s website were frequently cited as being important to external users. Several staff were aware of faculty and graduate students, educators, and fishermen that use SWMP data based on personal interactions:

I know of fishermen. When the SWMP stations were down after the storm [Hurricane Harvey], they kept asking when they would be up, because they would use the real-time weather data to understand winds and tides or water levels.

Management agencies with restoration projects in the Mission-Aransas Estuary were also identified as users of SWMP data. One staff member offered concrete examples of regulatory agencies using SWMP data such as the Texas Water Development Board (TWDB):

They passed Senate Bill 3 in Texas just about the time when we were a few years into having the Reserve. Senate Bill 3 required that every bay and basin system in Texas set up what was called a BBEST, a bay and basin expert science team, and then a bay and basin area stakeholders committee, a BBASC. For example, I was involved with the group that did that review for the Mission-Aransas estuary. We wrote an extensive report. Basically, we were given one year to review all the data that existed for our system, published data, and then to come up with recommendations for freshwater inflow as best we could, based on that. Those were passed on to the BBASC, the area stakeholders committee, and then we also worked with them to come up with their recommendations and then that report was then passed on to Texas Commission for Environmental Quality, TCEQ. Anyway, they *made the final recommendation. Basically, all our SWMP data was used to help define those freshwater inflow requirements.*

Beyond known uses of the data, a few staff members speculated about potential uses of SWMP data. Potential uses of SWMP data focused on surface elevation tables (SET) and wetland vegetation data that local organizations may find useful for understanding landscape change and guiding restoration needs.

Mission-Aransas staff face both organizational and personal challenges for operating the most successful monitoring program (Table 2.2: Challenges). While funding is a noted challenge, staff still believed the NERR does a good job with the limited budget they do have. The staff capacity at the Mission-Aransas NERR is another noted challenge that limits their ability to fully tackle SWMP and the expertise to be involved with specific projects that arise in the region. Staffing challenges can arise for a number of reasons such as salaries, turnover, and a disconnect in the priorities of the organization. Physical challenges, like weather, create challenging working conditions for field work. The SWMP water-based platforms are difficult to reach. Moreover, working at the vegetation sites means "*wildlife getting in the way—whooping crane season or snakes or alligators. There's just quite a few things that can throw off your field day.*" These monitoring locations are out of the public eye contributing to a larger challenge of visibility. Several staff see visibility of both the Mission-Aransas NERR and SWMP, specifically, as a need and a challenge. The multiple acronyms and affiliations can cause confusion even for locals. When the SWMP data is not disseminated well, it runs the risk of becoming insider information. One avenue for data dissemination and NERR communication is technology platforms. A few staff do not believe the current website is user-friendly and prevents the NERR from showcasing its best self:

I think a huge barrier is the number of websites and how confusing they are to link to each other. Even just starting with the UTMSI website and the NERR website, *it's very confusing. You see our faces on both, but people are very confused that the NERR is part of UTMSI. When you're communicating SWMP, they're like 'Wait, there's another thing going on here?'*

The visualization tools on the website serve an important purpose, but staff would like to see these visuals be understandable to a wider, non-scientific audience.

Faced with challenges, Mission-Aransas staff recognized solutions that are based on utilizing their strengths. Building relationships is central to these proposed solutions (Table 2.2: Proposed Solutions). Partnership is a strength of the Mission-Aransas NERR and over the years, the organization has established strong relationships for collaboration. If the Mission-Aransas NERR continues to leverage existing relationships while identifying new ones, this is a proposed solution to staff capacity and funding challenges. One important idea is to work to better utilize the Mission-Aransas NERR's partnership with the UTMSI and UT-Austin. Mission-Aransas staff can examine these horizontal partnerships and take advantage of their vertical relationship with NOAA. The NOAA and NERRS communities provide lessons learned and connection. One staff member highlighted the collaboration potential:

[N]ot just locally, but broad, like the NERR community. I think communication and trying to collaborate with people can help overcome a lot of those obstacles. A lot of times, you'll find someone that you never even thought about that has that answer for you, or they know somebody who has that answer.

The great diversity of NERRS should not prevent Mission-Aransas staff from connecting with other Reserves and searching for commonality. The virtual world holds promise for connecting across the nation and getting the Mission-Aransas NERR's message out. Social media is a great connector to reach new and existing audiences. The staff have an opportunity to increase the visibility of SWMP data on the website, specifically.

Finally, the university as a partner is a standalone theme because it touched on challenges, solutions, and the identity of the Mission-Aransas NERR (Table 2.2). The various Reserves have different state partners, including universities, state agencies, or nonprofits. Having an academic state partner comes with positives and negatives. One staff member summed this up nicely:

> *I think it gives us a lot more advantage in terms of the available expertise, and students and faculty that can address problems, but probably makes our connection with the end-users a little bit more remote. And there may be some financial limitations to that as well.*

The end-user separation translates to the critical yet time-consuming importance of outreach and partnerships for connecting SWMP data to management decision-making.

Partner Organizations

Thirteen individuals from Mission-Aransas NERR partner organizations were interested and available for focus groups. Three groups of four to five individuals took place with representation from the RAB organizations (Table 2.1). Individuals held various roles at their respective organizations including grants management, on-the-ground management, and project coordination. These smaller focus groups prevented dominant voices from overwhelming the discussion and allowed relatively in-depth responses to be gathered during the short time period (Berg, 2009).

Establishing the purpose or role of coastal management was an important first step to later build on its relationship with long-term monitoring (Table 2.3: Coastal Management). Individuals spoke to management's goal of promoting intergenerational (future generations) and intragenerational (multiple, current users) sustainability for coastal systems. Achieving sustainability may involve enhancing the existing environment, protecting against threats, and focusing on diversity as opposed to a preference for a single species or habitat. One state agency employee's observation represents the key to management: "*really what we're managing is human use and human impact of our natural* *resources more than we're managing our natural resources with themselves*." To promote the sustainability, management is about taking action. Managers are tasked with taking actions to achieve goals; this action-oriented mindset means managers may not have the time to analyze scientific data for decision-making. These decisions are often focused on the natural resources within an organization's jurisdiction. Describing the interplay between broad scale and local data, one nonprofit employee said, "*There's a lot of value in being able to tell that [environmental change] story on the national or regional basis. From a management perspective, though, I just deal with our little area.*" The site-specific nature of management work requires decision-making based in a local context. For the dynamic coastal environment, specifically, management must be based in science and responsive to environmental change. Managers should expect change and, if able to, utilize the change and work in concert with nature.

Long-term monitoring is one type of scientific evidence that drives the learning and response of adaptive management. Management agencies identified three main purposes for long-term monitoring in their work (Table 2.3: Importance of long-term monitoring). In all focus groups, individuals highlighted that long-term monitoring data provides the evidence for setting priorities. Priorities can take the form of program development or applying for funding based on areas or species of concern that need attention. Analysis of long-term data provides an avenue for informed management decisions. With long-term data, specifically, management can ensure they are not reacting to short-term phenomena:

> *I will say that state agencies can often be very reactive. So, while it may not be in our normal realm of work, now, to say, 'We're seeing this mangrove extent. What are we doing about it? What are we doing about mangrove expansion?' At this moment, not a whole lot. But as we start seeing more and more data come through in our long-term monitoring, then as an agency, we may be reactive to that.*

Long-term monitoring mitigates overreaction to short-term environmental change while still providing the opportunity to take action to a long-term change. Long-term monitoring programs also contribute to the inventory needed for evaluation. With baseline conditions and species previously monitored, management practices can be evaluated more accurately for success or failure. Simply put: "*You got to know what you have before you can manage. That's the bottom line.*"

When asked about their use of SWMP data, most individuals who were familiar with SWMP were indirect or secondary users of the data (Table 2.3: Impact- Known Uses of SWMP data). In general, those at the focus groups were not direct users in terms of analyzing the raw data and making decisions based off the analysis. One nonprofit employee described their involvement as:

> *[W]e'll do environmental indicators report where we gather up other people's information, including from the NERR, on water quality data and try to assess some long-term trends. […] It's really a higher altitude view of the data and the trends of what's going on. That's really our focus and how we're attempting to utilize that information in a management context.*

The SWMP data has been used in conjunction with other scientific evidence to understand long-term trends for grant applications. The managers often receive this information as summary data, or their colleagues may bring it their attention through other publications. Local and regional management will continue to have a need for long-term water quality data given the issues of drought and freshwater inflows for south-central Texas. Additional possible uses of SWMP data revolve around vegetation data, SET data, and habitat mapping (Table 2.3: Impact- Potential Uses of SWMP data). Habitat conversion is a concern for management, and habitat mapping and vegetation data could contribute to a further understanding of the issue. Habitat mapping fills a need: "*I think that habitat change has been difficult to find good, consistent, long-term datasets on.*" The implications of mangrove expansion and sea level rise on wetland habitat is also a concern with one federal agency employee pointing out:

> *I think, maybe some monitoring of a particular habitat type will help us in the future, is in the area of wind tidal flats. I'm not sure that we're going to create a whole lot of new wind tidal flats. Although at some point, I think we're going to have to figure out how to build them or manage them in some capacity.*

The Mission-Aransas NERR directly answers this call with the prior establishment of a wind tidal flat monitoring site. Finally, the SET data was frequently mentioned as potentially serving multiple purposes for the region, ranging from blue carbon work to ground-truthing habitat maps. Connecting the Mission-Aransas SET data with regionwide, ongoing SET work may prove relevant.

Barriers to successful monitoring encompassed funding challenges, nature of one's job position, and agency turnover (Table 2.3: Challenges). Funding was a repeatedly discussed, major challenge. Funding long-term monitoring is expensive and often loses out to the on-the-ground work of management which is believed to be more actionable, at least in the short-term. One nonprofit employee considered the disconnect between donors and long-term monitoring:

> *[I]t's that balance between funders wanting a short-term return on their investment and a tangible outcome versus the importance of this long-term data collection. Obviously, they recognize that the data is important, and it needs to be collected. But after the one, two, three-year funding that they provide, what can they tangibly say? What's the outcome? We have more data. So, it's hard to say, 'After X number of years, well, we can now implement certain management decisions' or something like that. You can't really make that claim from the beginning, because you don't know what the data will be.*

This uncertainty contributes to the difficulty in showing value of long-term programs. A challenge for using long-term monitoring for management is that, based on one's job position, they may not be the direct user of the data: "*A lot of times, the people who are collecting and immediately using the data are not necessarily the managers. Maybe there's* *a little bit of a disconnect.*" Management agencies have many directives and applying science to decisions is not their sole endeavor. The disconnection of management and monitoring data analysis has implications for its perceived relevance to decision-making. Within the management agencies, themselves, leadership turnover can shift management priorities. If monitoring shifts with the management, the collection of long-term information cannot be fully realized.

To receive funding and promote long-term monitoring, partnerships and showing value are two solutions (Table 2.3: Solutions). Showing value can take many forms—intentional, upfront linkage to conservation actions, better storytelling, and obtaining examples of use. Now is the time to show value as one partner observed:

> *I think with the involvement of ArcGIS and R and this online software development that you don't need a computer software degree for analysis. I think the long-term trends and, obviously, we're at a point where you can start seeing long-term trends in environmental data collection. I think the importance of monitoring, long-term monitoring, is improving, and people are starting to understand the importance.*

At times, showing the value of long-term monitoring leads to moving beyond one's management boundaries and working across jurisdictions. Managers can support one another through data collection efforts, lessons learned, and building community. In focus groups, individuals shared the belief that partnerships are a strength of the region and work well for addressing issues. Under a changing climate, reaching across boundaries instills the holistic view necessary to manage for the future:

> *And these climate concerns and loss of habitat… they [the Wildlife Refuges] were intended to be there in perpetuity, but if we're going to lose them, or they're going to be transformed to something different, we've changed the game. Those are serious thoughts for us as well. […] So, for us having these lanes with a nice boundary originally in mind, things are changing. They're not quite the same anymore.*

The focus groups ended with a discussion on the type of support the Mission-Aransas NERR staff needs to provide for actionable SWMP data. A few focus group participants reported being unfamiliar with the SWMP: "*I guess I would say, for me, I'm just not as familiar with it. Not to say that it's not useful or anything. I'm not even really that familiar with what it is and what it offers.*" Another state agency employee reminded, "*in each of our own agencies, our own internal communication isn't perfect. You can't just assume that because one person at an agency knows about your program that other people do.*" To begin to connect SWMP to the Mission-Aransas NERR partner organizations, data accessibility and data synthesis were two avenues for increasing visibility and connection (Table 2.3: Connecting SWMP to Partners). It is crucial that raw data remains accessible, easy to find and understand. The Mission-Aransas staff may even consider highlighting the local data separate from the CDMO website to reduce confusion. However, accessibility is a first step. Synthesis addresses the limited capacity managers have to run their own analysis and interpretation of the data. Moreover, support may go beyond providing a synthesis because, as one nonprofit employee believed, "*Showing a graph doesn't necessarily solve that manager's problem. There's a lot of things that go into interpreting that.*" Context about the long-term trends and potential causes is important for managers wanting to know the most appropriate practices to implement.

National NERR Representatives

Six individuals were initially identified through the interviewer's knowledge or referrals and contacted for an interview. Five responded with an acceptance to participate. These five national NERR representatives offered perceptions of the NERRS and SWMP (Table 2.4: SWMP and NERS perceptions) as well as challenges and opportunities. NOAA is the federal partner of all NERRS, and this national cohesion offers direction for moving forward. One individual took the view that the national level's purpose is to "*create a national identity that really reflects on the ground needs, but also is responsive to national priorities and national opportunities.*" The place-based nature of the NERRS means each has a level of flexibility in implementing these national priorities within the context of their local communities' needs. The four sectors of the NERRS—research, education, stewardship, and coastal training program—work together to understand and protect their estuarine environments. The Stewardship sector, as opposed to the other sectors, was not borne out of a defined national strategy:

> *Stewardship coordinators are more diverse, and so they do restoration. They do invasive species. They do sentinel site work, vulnerability assessments, land acquisition, and citizen engagement. So, it's not like we have a mandate, and there's not a uniform thing that everybody does.*

This diversity of priorities poses difficulty for the sector: "*Without uniform national objectives, it's difficult to identify measurable outcomes to justify targeted funding.*" The SWMP is a model and envy of other monitoring programs. The SWMP is the representation of a successful long-term, cross country monitoring program as the program has continued to increase their funding during challenging times. The CDMO and NERRS are called upon to help replicate similar programs. As a model, the usage of SWMP data has evolved:

> *The intended use of the monitoring program is still valid, but the actual usage of the data, these days, go beyond anything any of us dreamed about 25 years ago when we were first considering the establishment of this program.*

Although originally formed out of the need to understand long-term change and short-term variability in estuarine systems, the SWMP is used for a variety of innovative applications, either alone or with other datasets. The NERRS is not only understanding how SWMP data can be used for new external end users but also across its own sectors.

The national NERR representatives observed challenges that operate on individual Reserve and NERRS' levels (Table 2.4: Challenges). The Reserves are place-based by nature which poses an interesting challenge:

> *I think the beauty, and, for lack of a better word, the curse of the Reserve system, is that it's place-based which allows us to really celebrate the uniqueness of these places. It also means that each of them has their own individual challenges. They have different state partners, and a lot of what they do is driven by the mission of that state partner. That can be good—it can align totally with SWMP and the usage of its data and information, or they can be at odds.*

Leadership must ensure that top-down decisions align with the different state partners, and a solution for one NERR may not be the solution for others. The big NERR system is challenging to manage logistically and financially. Some Reserve state partners own the majority of their lands while others do not, like UT-Austin. Land ownership can provide its own challenges or not—SWMP data collection may not necessarily be simpler. Having access to land is also important for outreach and stewardship. Owning land does not necessarily put a NERR at greater advantage over another. For the NERRS, making SWMP actionable takes a huge effort. Reserves need the staff capacity to implement and operate programs as well as connect the data to those who need it. SWMP data is not accessible to decision-making in its raw form: "*We can't just give someone data and assume they're going to do something with it. They have to learn what that data means. They have to see what that data can provide them—what's its value.*" Working and supporting end users is necessary to develop tools for SWMP data to be accessible. Finally, personnel turnover can be a challenge for different NERR sectors. Representatives observed that turnover is sometimes a result of a lack of community support and engagement in the NERRS.

The national NERR representatives repeatedly spoke about challenges in terms of opportunities for the system and individual Reserves. Community in the system, across sectors, and across boundaries is key to pushing the NERRS forward and keeping SWMP relevant (Table 2.4: Opportunities). Creating community at the national level is imperative for the professional development and personal engagement of place-based staff. In a diverse system, community within sectors creates opportunity to share lessons learned, train, and increases each group's visibility within the NERRS. Outside of building community within their own sectors, individuals should build strong relationships across sectors to push SWMP forward. SWMP is cross-sectoral, and no longer isolated to the Research sector:

> *It's only been in the last decade or so that the other sectors within the Reserve system, including the education coordinators, the stewardship coordinators, the coastal training program folks, and the managers, have begun to fully or better utilize SWMP data. So now, SWMP is no longer considered a product or a program of the research coordinators within NERRS. The SWMP is recognized as a program within the Reserve system, itself. That's a pretty big deal.*

This shift translates to making SWMP fully actionable with each sector having a role in keeping SWMP relevant and visible to external users. However, this shift is not enough. The NERRS must be visible through relationships. Strategic partnerships keep the NERRS' message strong. The Science Collaborative, in particular, elevates the SWMP data for decision-making. A Reserves' work does not have to be used on-site to be relevant. SWMP and its applications and protocols can serve as a model beyond NERR boundaries:

> *We always talk about how it [SWMP]'s applied to the Reserve in terms of management, but, I think, even more exciting than that, is how does what you're seeing at Mission-Aransas relate to what you're seeing at Grand Bay or Weeks Bay or Rookery Bay, and how can you inform what's happening in South Texas, compared to what the northern Gulf of Mexico Reserves are seeing. I think that is really important even if there's a struggle about figuring out how to apply the data.*

Decisions are made at higher levels than a management's jurisdiction and thinking more broadly would serve a system like this well. Finally, there is an opportunity to use virtual platforms to build these relationships and stay visible. While not a replacement for the connection of in-person gatherings, virtual outreach should remain strong after the pandemic as it is inclusive for external groups that cannot physically travel to a Reserve and those within the NERRS that wish to build community.

DISCUSSION

Mission-Aransas NERR staff and their local management partners

The work of both the Mission-Aransas NERR and local management partners is perceived as grounded in science (Table 2.2; Table 2.3). The Mission-Aransas NERR serves as a research center for the Texas coast, and their outreach, education, and coastal training programs are based in science. For NERR staff, the long-term monitoring at the Mission-Aransas NERR was most closely related to the study and understanding of the Mission-Aransas Estuary. This research-centered perspective of long-term monitoring aligns with the Mission-Aransas NERR having a university state partner and little acreage to directly manage. The SWMP contributes to the staff's knowledge and is less explicitly tied to any decision-making on their part. In contrast, natural resource managers defined their work along the lines of action. To sustainably manage the coast and its natural resources, managers need to respond to the dynamic environment, and, therefore, long-term monitoring had a closer connection to their decision-making. Long-term data contributed to program development and restoration planning at their locations. It also provided a baseline to evaluate the actions and strategies managers undertake. Without the existence of a long timeframe of data, managers may evaluate their actions incorrectly or react to a short-term event with later consequences. Long-term monitoring contributes to higher-level decisions, such as goal setting, for management.

The SWMP data that partners are most interested in using are those that staff members identified as having potential for management needs—SET data, vegetation data, and habitat mapping. The datasets tie to not only issues of concern (i.e., mangrove expansion, invasive species) but also solutions (i.e., blue carbon sequestration). While the standardized water quality and nutrient data is important for the region, the terrestrial nature of several of the partners work supports their interest in these more recent SWMP parameters. These are not core SWMP parameters, and, thus, are not funded at the national level:

> *There have been Reserves now for about 10 years with sort of a voluntary vegetation monitoring, because we're [NOAA] not paying for that. It's not core SWMP. [… a challenge is] making sure that we're demonstrating how good the science is and what Congress and others will get, the regulators will get, in terms of vegetation response to changing sea levels, which is pretty important, especially for this administration.*

Through a strategic partnership with the Marine Global Earth Observatory (MarineGEO), a global network focused on understanding coastal marine biodiversity, it is a requirement at the Mission-Aransas NERR to collect estuarine emergent vegetation data. The staff has used core SWMP funds for the vegetation monitoring activities which allows the consistent collection needed for a robust dataset. This is an example of the value these collected and analyzed datasets would have to management needs and decision-making.

An Actionable System-wide Monitoring Program

Long-term monitoring programs may lose credibility and value if they are not tied to real-world impact on decision-making (Nichols and Byron, 2006). To overcome criticisms and demonstrate legitimacy, monitoring must be ingrained in conservation decisions with the input of end users early on (Lindenmayer and Likens, 2009). The System-wide Monitoring Program has elements of a strong long-term monitoring program, such as consistent protocols, data management, and a reliable funding structure (Hughes et al., 2017). Federal funding for long-term research has been historically rare (Callahan, 1984). While National Science Foundation (NSF) funding and number of awards for long-term studies decreased from 2004-2015, the short-term studies gained (Hughes et al., 2017). Local management noted that funding is always a challenge (Table 2.3). The NERRS offers its partners the consistent monitoring data that is often difficult to fund:

We have to make sure that, unlike most academic projects work on a three-year cycle, or if they're lucky five-year grant cycle, we're coming on to the second decade of consistent funding and so that's what makes a huge difference. [...] Fortunately, we've been able to do that really well, and we've gotten a lot of increases over the past few years, even through challenging funding times.

The SWMP is situated in a sustainable multi-level structure as it operates out of each Reserve but is strategically directed at a national level (Berkes and Folke (Eds.), 2003). As a place-based organization, the Mission-Aransas NERR can contribute local data to management which fits best with their on-the ground needs. Fit within the NERRS, the SWMP contributes to understanding the Mission-Aransas Estuary in a broader context. In this way, the Mission-Aransas staff is able to understand the nuances and complexity of their social-ecological system (Berkes, 2009).

All three groups interviewed agreed about the importance of long-term monitoring (Table 2.2-2.4), but the question remains whether long-term monitoring is the central conduit to decision-making. While not directly asked by the interviewer, it was understood that other types of evidence were used for management decision-making. Depending on the institution and one’s role within the institution, sources like the media (television and internet), anecdotal evidence, or peer-reviewed publications on short-term studies may be the conduit to understanding an issue and making decisions (Gray et al. 2014). Management decision-makers may not use scientific information if it is not apparent how it connects to decisions they need to make (Maxwell et al., 2015). Some questions may not be answered with scientific information (Salafsky et al., 2019), and values may drive the decisions managers make (Allen et al., 2011; Schuurman et al., 2020). Managers may value specific ecosystem services and expend their efforts to conserving those habitats which provide the greatest number of services.

The shift to make SWMP cross-sectoral (Table 2.4) continues to improve engagement of decision-makers and science education for younger students—additional elements of a sustainable monitoring program (Hughes et al., 2017). The Coastal Training Program (CTP) has an important role in overcoming the barriers that separate scientists and decision-makers for knowledge exchange to take place (Cvitanovic et al., 2016). CTP plays a role in making SWMP actionable:

> *What data was useful 20 years ago, may not be useful to answer the questions of tomorrow. I think that's the crux of every long-term monitoring program, is that you want to make sure it stays relevant. There's beauty in this long-term data set, but you got to make sure that you continue to collect the right information. And I think that's what's so great about the relationship between SWMP and CTP, is that CTP, they are the program that will ensure it stays relevant. That it doesn't just get locked in the ivory towers of academia. That it actually is being connected to decision-makers.*

Focusing on this knowledge exchange can lead to partnerships, increase the NERRS' visibility, and provide connections beyond the Mission-Aransas NERR place-based boundaries.

Making science impactful takes conversations to learn about the audience, their need for evidence, and the most effective ways to deliver that evidence for action (Fisher et al., 2020). Personal interactions, while time consuming, are important for promoting science for action and identifying the preferred information source to highlight long-term monitoring data (Seavy and Howell, 2010). Often times, management practitioners and expert scientists are separated (Berkes and Folke (Eds.), 1998), but the process of knowledge exchange links the two groups' perspectives on issues (Gray et al., 2014). Management practitioners may not have the capacity to analyze long-term data or access scientific literature that uses long-term data (Walsh et al. 2014). Creating synopses or summaries of scientific information for management, as discussed in the focus groups, is key to influencing management practices (Walsh et al., 2014).

The Education sector, likewise, plays an important role in connecting long-term monitoring data to everyday application. Integrating SWMP data into Teacher on the Estuary (TOTE) workshops, or field and research-based training for teachers, creates a "*domino effect*" in which the education program works to "*get the teachers out there, get them excited, then they'll bring their kids back. Then, hopefully the kids will get excited, and they'll bring their parents to an outreach event.*" When children and adults gain environmental and scientific literacy, communities are stronger (Bey et al., 2020). This community resilience contributes to the overall social-ecological system resilience necessary to respond to climate change and other complex issues.

All sectors at the Mission-Aransas NERR have a role in making SWMP not only operational but actionable. Knowledge exchange should be an indicator that is evaluated and measured to most accurately define SWMP success.

Focus Group Selection Bias

Given the study's timeline and need to target a more specific group of decision-makers, those organizations represented on the Mission-Aransas NERR Reserve Advisory Board were selected for focus group recruitment. These organizations may own or manage natural resources within the Mission-Aransas NERR boundaries. While some of these organizations reported using Mission-Aransas required SWMP data, like water quality and nutrients, the land-based nature of others' work has prevented them from taking advantage of those datasets. Local government officials, while represented on the RAB, did not participate in focus groups; Mission-Aransas staff should consider how to engage these policymakers with long-term data.

There are important stakeholders that have and continue to use SWMP data but do not serve on the RAB. These regulatory agencies, volunteer groups, and more work within the boundaries and have close relationships to Mission-Aransas NERR programs, including SWMP. Three regulatory agencies in particular—the Texas Water Development Board (TWDB), Texas Commission for Environmental Quality (TCEQ), and the U.S. Environmental Protection Agency (EPA) are important users of SWMP data for their decision-making. The SWMP water quality data has been particularly instrumental in freshwater inflow policymaking in Texas. Additional groups with known uses, like fishermen and universities, were also discussed during Mission-Aransas staff interviews but not included for focus groups. This study did not seek to answer what the relationship is between long-term monitoring and decision-making for all types of groups, and, instead, maintained a narrow focus on NERR partners in a management context. These additional stakeholders must be included in knowledge exchange efforts and further engagement with SWMP especially as there are concrete examples of their SWMP usage and potential lessons to be learned from their experience.

CONCLUSION: LOOKING FORWARD AND RECOMMENDATIONS

Science has a responsibility to respond to issues affecting social-ecological systems (Kotchen and Young, 2007). Monitoring contributes to what is known about the environment (Berkes and Folke (Eds.), 2003), and the SWMP currently only monitors environmental parameters. Scientists and management must take care to select appropriate indicators so that they are learning the right things and detecting change (Armitage et al., 2009). To fully respond to wicked problems, human dimensions need to be included in monitoring so that a full understanding of coupled social-ecological systems can be developed (Kotchen and Young, 2007). One federal agency employee identified the need for this monitoring:

> *[M]aybe there are some things we can monitor that we're not yet monitoring. I'm talking about the users of these resources. We tend to focus on the resource. We monitor it because it doesn't have a voice. We are the voice for that resource, but users… they change over time.*

Expanding SWMP to consider the social of social-ecological systems is under consideration at the national level; however, these discussions are only part of brainstorming, and actual implementation is not likely in the near future. Likewise, the Mission-Aransas NERR is considering the incorporation of ecosystem services into SWMP (UTMSI, 2021).

All groups see the potential to elevate SWMP data to reach its fullest potential. Collaboration among and resources at the national level offer opportunities for Mission-Aransas staff to apply their data. The NERRS Science Collaborative funding program has evolved since its establishment in 1997 to better meet the needs of end users (Trueblood et al., 2019). The program funds science for coastal management usage and explicitly calls on collaboration to elevate end users (Trueblood et al., 2019). As the primary responsible party of the Science Collaborative, the CDMO has an outlook that this opportunity

> *now allows [them] to fully engage with all of the projects associated with the Science Collaborative. That's really cool because it increases both the use of SWMP data but also demonstrates the greater value of all of the SWMP data.*

The Science Collaborative funds some projects that have a focus area in 'Application of SWMP Data.' Projects include statistical application development to understand water quality trends, region-wide comparisons of marsh vegetation change, and the creation of workflow guides for surface elevation table visualizations (The Regents of the University of Michigan, 2021). Tool development and application to end users are imperatives of the Science Collaborative. Leveraging the skills of Reserves beyond Mission-Aransas can be a channel for connecting SWMP data to management.

The following recommendations provide a path forward for Mission-Aransas staff, partner organizations, and/or NERRS to promote their work and SWMP. These recommendations align with ongoing work that the different groups may already be pursuing.

Recommendation 1: Further engage University of Texas Marine Science Institute faculty and students not only as data users but also as storytellers.

The Mission-Aransas NERR's state partnership is a recognized strength. This connection provides an avenue for students and faculty to share their expertise to solve coastal management issues. While the Research sector has programs for engaging graduate and undergraduate students (UTMSI, 2021), staff recognized that the NERR can continue to better utilize this relationship with the University. Taking advantage of the researchers and facilities at UTMSI can build connection between the NERR and the University (Dunning, 2019). University researchers are a primary user of the Mission-Aransas NERR for their studies (UTMSI, 2021). In general, SWMP data is mostly used for research purposes (64.8%) by researchers, graduate, and undergraduate students (76.9%) as opposed to for management purposes (2.4%) by those who designate themselves as managers (0.2%) (CDMO, 2020). This recommendation leverages the Mission-Aransas NERR's strength of partnership and tackles challenges such as staff capacity and making the NERR and SWMP known. This relationship can benefit the multiple parties involved. Students and faculty have the potential to serve as SWMP data users as several currently do and have in the past. Most importantly, through enhanced connection, the Mission-Aransas NERR is building stewards who will take their message throughout the student's graduate time and into their career. The Mission-Aransas NERR can also provide a platform for students and faculty to connect with external partners for connecting science to decisions. The NERR can be a conduit and provide introduction for informational interviews and meetings to understand how a student's interest align with priorities and actions in the Mission-Aransas NERR management plan and the plans of other management agencies. Although academics face institutional barriers to collaboration, demonstrating the importance of academia to applied, end-user involved research will highlight the influence of the NERRS, and, hopefully, highlight these relationships as metrics of success in academia (Wowk et al., 2017). Academics serve an important role in producing science and may be key in translating SWMP data to management needs:

> *Most managers probably do not have the time to do that. I think oftentimes you might have academics using the data and then managers using the information that academics generate to manage the resource. Because of that degree of separation, maybe it's hard to show the impact or the benefit of having that data available.*

The Mission-Aransas NERR can provide training for students and faculty interested in translating their research into synopses or summaries for management. Researchers can return to the Mission-Aransas NERR staff with their stories of connecting SWMP data to end users and provide evidence for the importance of long-term monitoring. Finding ways to build community, whether through casual meetups or dedicated events, increases the stories these scientists can go forth and champion. As the Mission-Aransas NERR furthers its engagement with UTMSI, they can evaluate how these efforts in relation to other local institutions, such as the Harte Research Institute and Texas A&M Universities.

Recommendation 2: Collect stories to build institutional knowledge and show value.

When discussing SWMP data usage, several staff commented that they were unsure of how data was used or disseminated. Examples include: "*I know they use it, but I don't know how they're using it"* and

> *I mean speaking honestly, you asked me the question of how it's getting disseminated, and I don't know if it's the lack of me not asking enough questions about it, but I honestly don't know except from the professors that I work with personally in the labs and their projects, which is a big part of who uses our data.*

Collecting examples of the SWMP data's contribution to decision-making demonstrates the program's relevance that can then be communicated by any staff member. As the majority of Mission-Aransas staff are communicators, everyone having access to this knowledge is important. Building institutional knowledge works against the challenge of turnover—when staff leave, their stories remain with the Mission-Aransas NERR. Long-term monitoring programs may be even more crucial to those organizations with high turnover by creating a record of ecological change that any one employee is not responsible for holding. In this way, collecting stories is a form of knowledge exchange and knowledge transfer. Stories of the long-term monitoring program use or the long-term change itself should continue to be recorded for building this knowledge. As a first step, collecting stories of use also provides a standard to measure future examples on. Mission-Aransas staff can learn from each other and consider ways to continue to connect the data to decisions. Because of the disconnect in managers reporting directly using the data, and most staff having their own experiences communicating the data to end users, the staff may not learn about SWMP usage without consistently relaying those stories to one another. This knowledge can also provide the basis for a template or consistent speech that everyone can share in their communication activities. Showcasing concrete and potential uses of SWMP data to different audiences demonstrates how long-term monitoring can be for everyone. Past efforts to build knowledge, such as Evans et al. (2012) *The Ecology and Sociology of the Mission-Aransas Estuary: An Estuarine and Watershed Profile*, provide guidance for continued efforts. Gathering this knowledge is imperative for the constant struggle in obtaining funding for long-term programs.

Recommendation 3: Fund non-core SWMP activities as the data increases in importance with climate change.

Water quality and nutrient data have defined roles in the policymaking of regulatory agencies given this region's historical issue of freshwater inflows. As sea level rise and mangrove encroachment continue to become larger concerns for the area, data collection, analysis, and delivery are becoming increasingly important and needed as shown in the focus groups. The Mission-Aransas NERR has leveraged their funding to support vegetation monitoring which has led to the consistent data collection for the past decade. Additional funding at the federal level would allow the monitoring to not only be operational but also more actionable. In the meantime, the Mission-Aransas NERR can seek collaborative pathways for delivery of the synthesized data. Further understanding the data delivery and use by the TWDB, TCEQ, and stakeholder groups may provide lessons as the staff considers how vegetation and elevation data can play a similar role for policy or management. Identifying similar vegetation programs part of the RESTORE Council Monitoring and Assessment Program (CMPA) in the Gulf of Mexico (NOAA and USGS, 2020) can lead to partnerships and best avenues for connecting this monitoring data to those who need it. The Stewardship program at the Mission-Aransas NERR is strong in partnerships and currently serves in advisory capacities for several local and regional workgroups. An examination of these existing advisory roles and potential ones can provide strategic direction on the best avenue for moving this place-based data beyond the Reserve's boundaries.

Recommendation 4: Embrace technology after COVID-19.

Mission-Aransas NERR staff and national NERR representatives noted that virtual platforms should and will continue to play an important role in communication. The virtual platform makes moving beyond boundaries easier and allows individual Reserves to connect to the national network and create community. While balancing place-based interactions, the Mission-Aransas staff can embrace technology to embrace inclusivity. Cost and travel time have historically been noted as concerns for meetings and trainings, especially for those in more remote areas of the south-central Texas region (Leister and Morehead, 2009). The virtual platform has the potential to reach more people and increase the visibility of the Mission-Aransas NERR. The virtual platform can also be expanded to include website revisions and social media productions highlighting the multiple uses of SWMP data.

Table 2.1. Organizations with a representative on the Mission-Aransas NERR Advisory Board. Some of these partners own or manage natural resources with the NERR boundaries and were recruited to participate in focus groups. Asterisks signify a representative(s) participated in the focus groups.

Mission-Aransas NERR Partner	**Organization Type**
U.S. Fish and Wildlife Service*	Federal agency
Texas General Land Office*	State agency
Texas Parks and Wildlife Department*	State agency
Texas Department of Transportation*	State agency
Coastal Bend Bays & Estuaries Program*	Nonprofit
Coastal Bend Land Trust*	Nonprofit
The Nature Conservancy*	Nonprofit
Fennessey Ranch*	Private business
Aransas County	Local government
City of Rockport	Local government
Aransas County Navigation District	Local government

Table 2.2. Themes from staff interviews (n = 7). Themes were included as they related to one of the major categories for SWMP evaluation. The number of unique interviewees who discussed the theme are included.

Categories & Themes	Number of Interviewees
University as a Partner	5
Role of Mission-Aransas	
MANERR is scientific support for community	7
MANERR is an indicator estuary	4
Importance of long-term monitoring at MANERR	
Develop baseline database for the past and present	7
Validation of visual assessment	2
Point to the need for more research	2
MANERR or others can make informed decisions	2
SWMP Perceptions	
Communication takes many forms but is often embedded in general NERR communication	5
SWMP isn't what makes MANERR exciting to the public	4
Upfront efforts mean we have a great database	4
Impact: Known Uses of SWMP data	
Faculty and students use water quality data	5
Fishermen use real-time data	4
Educators use real-time data and water quality data	3
Regulatory agencies use water quality and nutrient data	3
Management agencies use water quality and meteorological data	2
Impact: Potential Uses of SWMP data	
SET and Vegetation data to understand landscape change and restoration action	3
Challenges	
Staff Capacity	6
Making the NERR and SWMP known	5
Monitoring locations	5
Technology is not user friendly	4
Weather issues for field work	3
Funding to do more projects	2
Proposed Solutions	

Lean on the National Network	7
Take advantage of the virtual world	6
Partnership is our strength	5

Table 2.3. Themes from partner focus groups (n = 3). Themes were included as they related to one of the major categories for SWMP evaluation. The number of unique groups who discussed the theme are included.

Categories & Themes	Number of Groups
Coastal Management	
Manage for sustainability	3
Management is about taking action	3
Science-driven management responds to changes in the environment	3
Management is often place-based	3
Importance of long-term monitoring	
Highlights what needs attention	3
May prevent reactions to short-term phenomena	2
Provides a history for evaluation	2
Impact: Known Uses of SWMP data	
Indirect Summary use	3
Impact: Potential Uses of SWMP data	
SET data can serve multiple purposes for the region	2
Vegetation data connects to relevant issues	2
Habitat mapping would serve a need	2
Water quality will always be important to the region	2
Challenges	
Long-term monitoring loses funds	3
Management may not be the direct user	3
Shifting priorities from leadership	2
Solutions	
Work beyond your boundaries	3
Connect monitoring to action to show value	2
Connecting SWMP to Partners	
Data accessibility	3
Data synthesis with context	3

Table 2.4. Themes from NERR interviews (n = 5) Themes were included as they related to one of the major categories for SWMP evaluation. The number of unique interviewees who discussed the theme are included.

Categories & Themes	Number of Interviewees
SWMP and NERRS perceptions	
The usage of SWMP data has evolved	5
National Cohesion with Individual Implementation	4
The SWMP is a model	2
Challenges	
Diversity of many Reserves	5
Making SWMP actionable is a huge effort	5
Turnover	2
Land ownership	2
Opportunities	
Make the System visible through relationships	5
Create community within sectors	4
SWMP is cross-sectoral	4
Importance of virtual platforms	3
Move beyond site boundaries	2

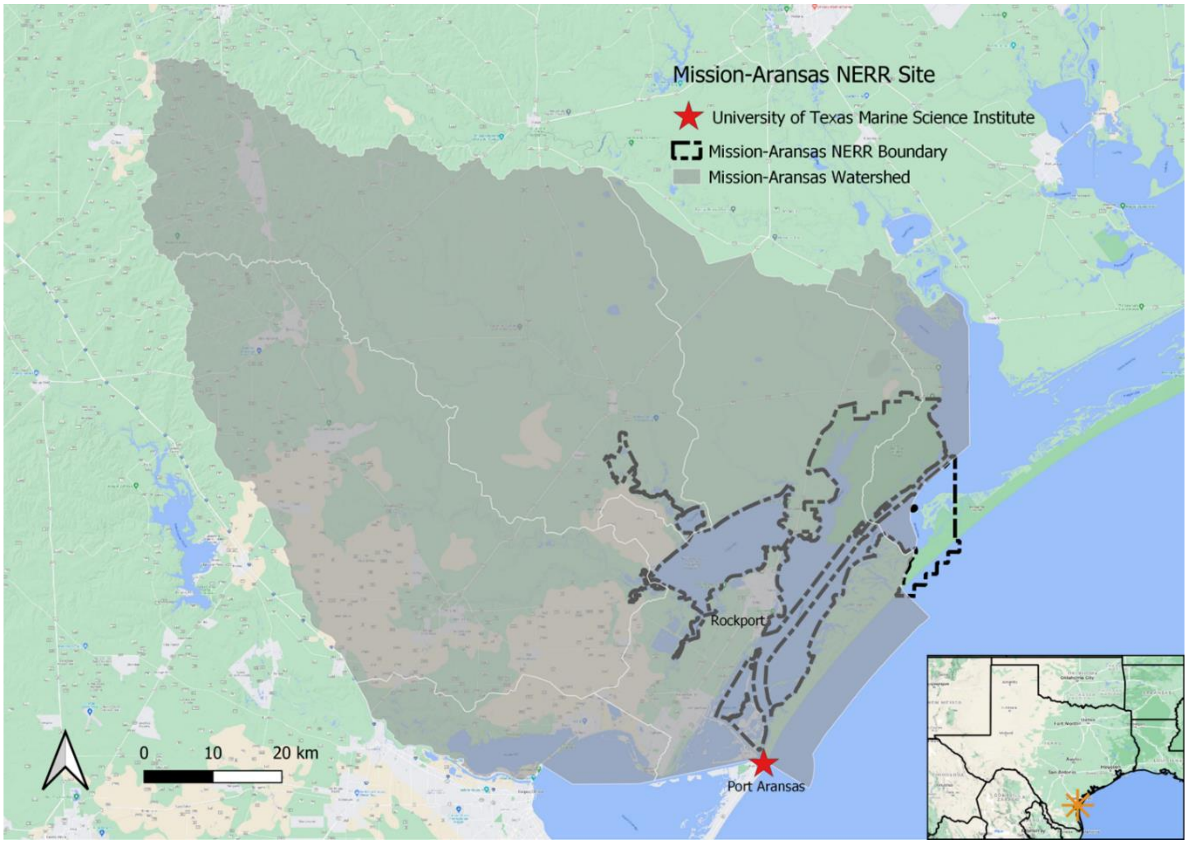

Figure 2.1. The University of Texas Marine Science Institute (UTMSI) is the state partner of the Mission-Aransas National Estuarine Research Reserve (NERR). While long-term monitoring takes place within the Mission-Aransas NERR boundaries, human impacts from the entire watershed influence the ecological health.

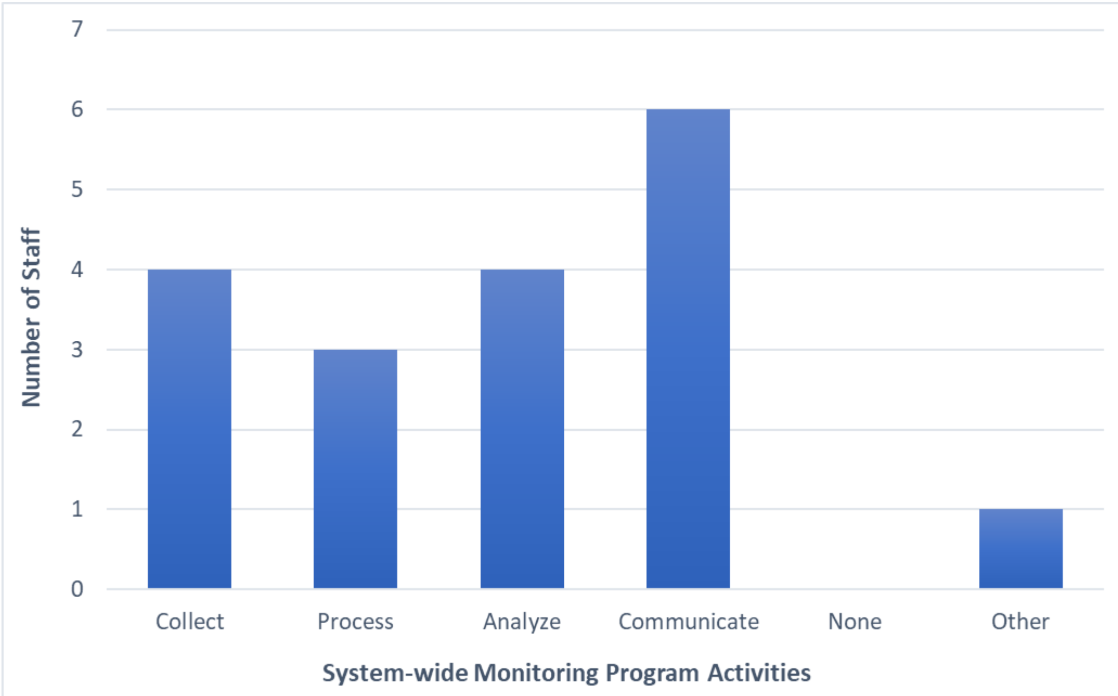

Figure 2.2. The System-wide Monitoring Program activities that Mission-Aransas staff currently participate in or have participated in (2017-present). Responses were collected on Qualtrics survey platform (Appendix B). (n = 7 staff members)

Appendices

Appendix A. University of Texas at Austin Institutional Review Board Exempt Determination

The University of Texas at Austin

Office of Research Support & Compliance
Institutional Review Board
P.O. Box 7426, Campus Code A3200
Austin, Texas 78713
T: 512-232-1543 F: 512-471-8873
Email: irb@austin.utexas.edu
www.research.utexas.edu/ors

EXEMPT DETERMINATION

January 29, 2021

FWA # 00002030

Kathleen Swanson
750 CHANNEL VIEW DR
PORT ARANSAS, TX 78373

+1 361 749 3106
kms2526@eid.utexas.edu

Dear Kathleen Swanson:

On 1/29/2021, the IRB reviewed the following submission:

Type of Review:	Initial Study
Special Determinations:	Waiver of consent documentation
Title:	Monitoring for Resilience: Emergent Vegetation Dynamics in the Mission-Aransas NERR Social-Ecological System
Investigator:	Kathleen Swanson
IRB ID:	STUDY00000642
Funding:	None
Grant ID:	None
IND, IDE, or HDE:	None
Approval Date:	1/29/2021
Documents Reviewed:	• Focus Group Consent Form, Category: Consent Form; • HRP-UT902-Exempt, Category: IRB Protocol; • Recruitment email for Focus groups, Category: Recruitment Materials; • Recruitment email for Survey/Interview, Category: Recruitment Materials; • Semi-structured focus group, Category: Other; • Semi-structured Interview, Category: Other; • Survey on Recruitment email, Category: Recruitment Materials;

Page 1 of 2 Template Revision: January 6, 2020

The University of Texas at Austin

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www.research.utexas.edu/ors

	• Survey/Interview Consent Form, Category: Consent Form;

The IRB determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104 (2)(ii) Tests, surveys, interviews, or observation (low risk).

In conducting this protocol you are required to follow the requirements listed in HRP-103 - INVESTIGATOR MANUAL.

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. Modifications that involve a change in PI, increase risk, or otherwise affect the exempt category or the criteria for exempt determination must be submitted as a modification. Investigators are strongly encouraged to contact the IRB staff to describe any changes prior to submitting an amendment.

If you have any questions, contact the RSC by phone at 512 -232-1543 or via e-mail at irb@austin.utexas.edu.

Sincerely,

Institutional Review Board

University of Texas at Austin

cc:
Kathleen Swanson (PI), Miranda Madrid (Primary Contact), Miranda Madrid (Proxy)

Appendix B. Mission-Aransas NERR Recruitment Survey on Qualtrics

MANERR Recruitment Survey

Start of Block: Default Question Block

Q1
The purpose of this survey is to identify those on the Mission-Aransas NERR staff who are both familiar with the System-Wide Monitoring Program and participate in at least one step of the monitoring process (i.e., collection of the data).

The System-Wide Monitoring Program includes the five water quality monitoring stations, the two meteorological stations, nutrient and plankton collections, emergent marsh and mangrove annual monitoring, and surface elevation table monitoring.

Please read the terms of consent before proceeding.
Informed Consent

Do you consent to these terms?

○ Yes (1)

○ No (2)

Skip To: End of Survey If No

Q2 Name

____

Q3 Position/Job Title

____

Q4
Which System-Wide Monitoring Program activities do you currently participate in or have participated in (2017-present)? Select all that apply.

- ▢ Collect data in the field (1)
- ▢ Process data back in the lab (2)
- ▢ Analyze data in your computer program of choice (3)
- ▢ Communicate (written and/or verbal) data to end users (can include educators, land managers, volunteer groups, community members). It's possible to communicate the results of existing SWMP data OR about the SWMP itself and potential value to end users (4)
- ▢ None of the above (5)
- ▢ Other (6)

Q5
How often do you participate in the System-Wide Monitoring Program activities on an annual basis? (Examples: once a month, once a year, all during summer field season, etc.)

____
____
____
____
____

End of Block: Default Question Block

APPENDIX C. INTERVIEW GUIDE FOR MISSION-ARANSAS NERR STAFF

Aim: 40-60 minutes

- Welcome: Thank you for agreeing to the interview.
- Review Informed Consent.
    - Ensure that interviewees understand the purpose of the study, the interview process, and how they're responses will be used in the report.
- Ask: Are there any questions at this time? They can also ask during the interview or afterwards.
- Obtain verbal consent and begin audio-visual recording on Zoom.

<u>Mission-Aransas, SWMP, and You</u>

- In your own words, what is the Mission-Aransas NERR's mission?
- How does our monitoring program (SWMP) support this mission you've shared?
- According to the survey, you participate in [X] activities. Can you tell me more about that?

<u>Partner Perceptions (can broaden to non-NERR, external users]</u>

Can encourage interviewees to speculate or consider potential uses if they do not know actual uses.

- How do our partners use this data?
- How do our partners get the data?
- Does SWMP data influence decisions they make?
- Does the SWMP data we collect address their concerns?

<u>Moving Forward</u>

- What does the Mission-Aransas team do best?
- What are barriers to monitoring efforts?
- How can these barriers be addressed?

- Provide space for: Is there anything you'd like to add?
- Thank you again. Follow up:
    - May I follow up with you if I have questions?
    - I will send an email by the end of the day with a 'final' request.

The next step is focused on Mission-Aransas NERR partner organizations. I have compiled a list of individuals who I plan to recruit.
1) Is there anyone not on this list who is integral to include in my recruitment email?
2) Who are the high priority individuals/organizations to contact?
3) Is there anyone on this list who should not be recruited for participation?

APPENDIX D. FOCUS GROUP GUIDE FOR PARTNER ORGANIZATIONS

Aim: 1.5 hours

- Welcome: Thank you for agreeing to join the focus group.
- Review “Agreements for Virtual Focus Group” establishing group norms.
- Icebreaker introductions.
- Review Informed Consent.
    - Ensure that group members understand the purpose of the study, the focus group process and facilitator role, and how they’re responses will be used in the report.
    - Emphasize confidentiality for focus group members.
- Ask: Are there any questions at this time? They can also ask during the focus group or afterwards.
- Obtain verbal consent and begin audio-visual recording on Zoom.

<u>Land/Natural Resource/Coastal Management</u>
To start general, establish a common understanding among participants of the purpose of their management roles (Round robin to hear from everyone).

- In your own words, what is the goal of coastal management?
- How do long-term monitoring programs support this goal?

<u>Mission-Aransas and SWMP</u>
Discuss your relationship with SWMP data and understand its impact on your work. SWMP is water quality, nutrients, weather, vegetation, SETs, plankton, and habitat mapping in Mission-Aransas Estuary.

- Raise your hand if you have used or currently use SWMP data in your own work.
    - How? What do you find most useful from SWMP? Did you use the data to make a decision?
    - Are there reasons you do not? What are some potential uses?
- What is the importance of local data vs. regional vs. national—What spatial scale of data or data synthesis do you use to make decisions?
- What questions or issues of concern does SWMP data address, or would you like to see SWMP data address?
- What is the importance of local data vs. regional vs. national—What spatial scale of data or data synthesis do you use to make decisions?

<u>Your Organization’s Monitoring</u>
Time to hear about your long-term monitoring programs (personally or organization wide). This information may help with future collaboration across the Coastal Bend, Texas.

- Does your own organization have long-term monitoring? What do these activities look like?
- Do you have guidance documents that inform you organization's monitoring? Tell me about them.

Looking Forward

Last topic. Ending on barriers, challenges, and solutions. How we look forward to solving physical, institutional, and other challenges.

- What are barriers and challenges to monitoring efforts?
- How do you think these barriers/challenges can be addressed?
- What level of support would Mission-Aransas need to provide to you for SWMP data to be used?

➢ Provide space for: Is there anything you'd like to add?

➢ Thank you again. Follow up:
  - May I follow up with you if I have questions?
  - I will follow up if you are interested in joining my thesis presentation in late summer.

APPENDIX E. INTERVIEW GUIDE FOR NATIONAL NERR REPRESENTATIVES

Aim: 40-60 minutes

- Welcome: Thank you for agreeing to the interview.
- Review Informed Consent.
    - Ensure that interviewees understand the purpose of the study, the interview process, and how they're responses will be used in the report.
- Ask: Are there any questions at this time? They can also ask during the interview or afterwards.
- Obtain verbal consent and begin audio-visual recording on Zoom.

After speaking to Mission-Aransas staff, I realized the need to contextualize SWMP and the NERR as a National Network. As a System-wide informant, I would like to hear your own thoughts and what you've observed and heard from other NERRs in regard to System-wide perceptions, opportunities, and challenges.

- Tell me about your role in the NERRS. What does this role entail?
- In your own words, what is the mission of your group?
- How does SWMP support or relate to this mission?
- What challenges have most often been brought to you or you've observed related to your group's work with SWMP?
- How has your group addressed these challenges? Any lessons learned along the way?
- Have you observed differences in your group based on their type of partner? If so, what?
- What does your group do well for connecting SWMP data to management? Are there any areas of improvement?
- Future directions: How does your group envision SWMP's role in their future work?

- Provide space for: Is there anything you'd like to add?
- Thank you again. Follow up:
    - May I follow up with you if I have questions?
    - I will follow up if you are interested in joining my thesis presentation in late summer.

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